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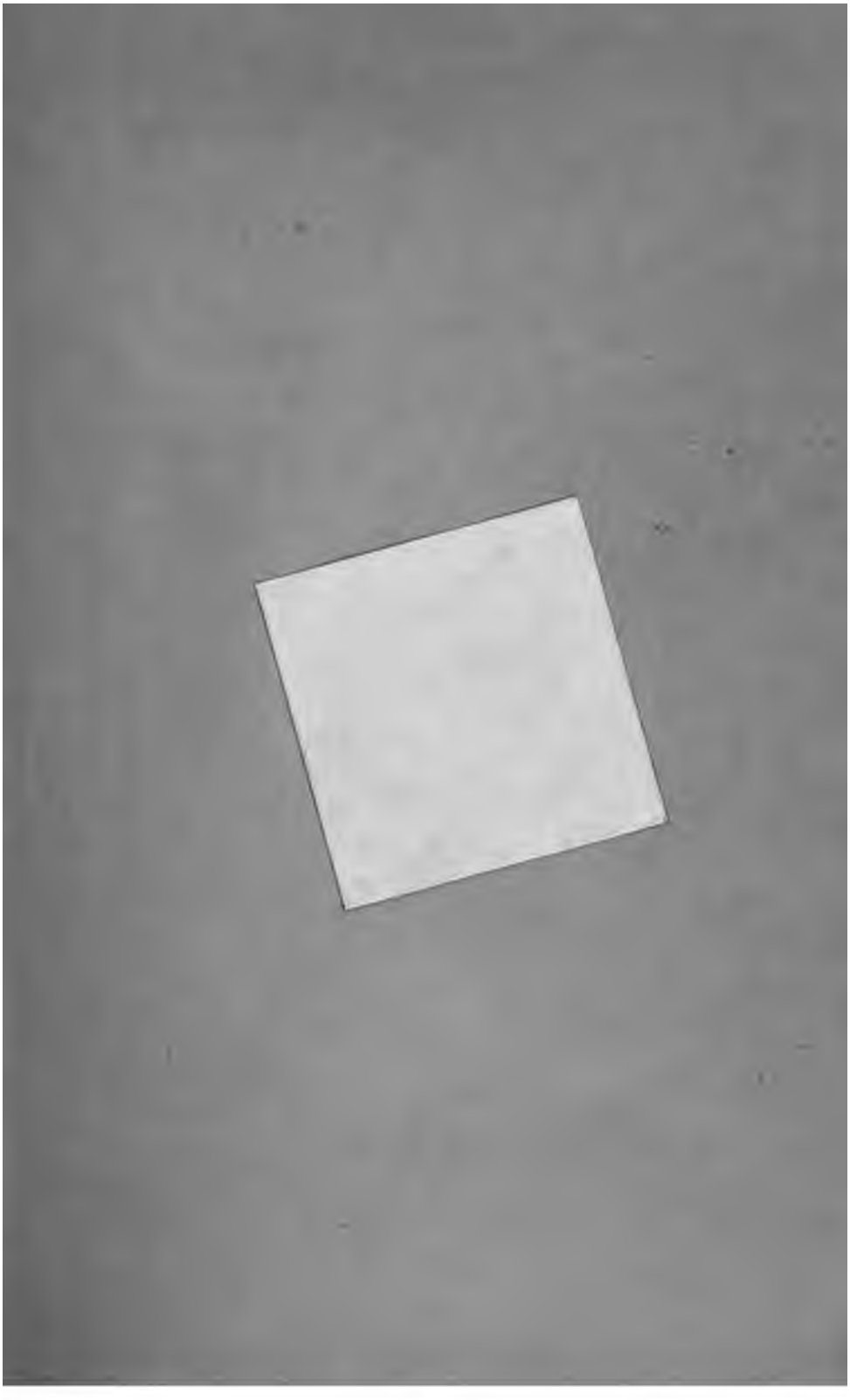

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DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

REPORT OF PROGRESS

IN THE

GEOLOGICAL RESURVEY OF THE CRIPPLE CREEK DISTRICT, COLORADO

BY

WALDEMAR LINDGREN AND FREDERICK LESLIE RANSOME

WASHINGTON

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., November 3, 1904.

SIR: I have the honor to transmit herewith the manuscript of a preliminary report on a "Resurvey of the Cripple Creek district of Colorado," by Messrs. Waldemar Lindgren and F. L. Ransome, under my general supervision.

Although only ten years had elapsed since a careful study of the geology of this district was made by Messrs. Cross and Penrose, the people of Colorado had been so strongly impressed with the economic importance of a scientific examination of the ground opened by mining operations during that period, that they urgently requested this resurvey and have materially assisted in its execution.

The present report, made in advance of the final laboratory examinations, is a summary of those facts that bear upon the economic development of the region and are of immediate importance to the miners. I therefore request that it be published with the least possible delay, that its results may be promptly available to all interested in the region.

Very respectfully,

S. F. EMMONS,
Geologist in Charge Section of Metalliferous Deposits.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

REPORT OF PROGRESS IN THE GEOLOGICAL RESURVEY OF THE CRIPPLE CREEK DISTRICT, COLORADO.

By WALDEMAR LINDGREN and FREDERICK LESLIE RANSOME.

INTRODUCTION.

The Cripple Creek gold deposits were discovered in 1891. Shortly afterwards, in 1894, an examination of the new district was undertaken by the United States Geological Survey, Mr. Whitman Cross having charge of geology and petrography and Mr. R. A. F. Penrose, jr., undertaking the examination of the mines. Their report, accompanied by a geological map, was published in the Sixteenth Annual Report of the Geological Survey, Part II, pages 1–207, and has for the last ten years served as a useful and accurate geological guide to mining operations.

With the astonishingly rapid development of the Cripple Creek mines the opportunities for geological study multiplied, revealing great complexity of vein phenomena and stimulating a desire for further investigation, particularly with a view of obtaining some evidence as to the persistence of the veins in depth. This desire found expression in a request by citizens of Colorado for a reexamination of the district by the United States Geological Survey and in an offer of cooperation, whereby the cost would be equally divided between the State of Colorado and the National Survey. The necessary amount having been subscribed in Cripple Creek, Colorado Springs, and Denver, the State contribution was put in the hands of Mr. John Wellington Finch, State geologist of Colorado, and by him disbursed. The cordial thanks of the geologists in charge of the work are due to Mr. Finch for his hearty and efficient cooperation.

The reexamination began with a thorough revision of the topographic map of Cripple Creek by Mr. R. T. Evans, Mr. E. M. Douglas in charge. This involved a great deal of painstaking work, nearly every prospect hole being located, as well as all shafts and tunnels. The new map is on the scale of 1:19,495, or about 2½ inches to the mile, and includes practically the same area as the old map, a small strip only being added on the western side, so that the total area mapped is about 40 square miles. The small developments outside of this area

did not seem to justify further extension of the boundaries. Contours are 50 feet apart, and a numbered list of 324 mines is given on the margin of the sheet. A line of accurate levels was run to Cripple Creek from Colorado Springs, thus settling the conflicting data of the different railroads.

The geological and mining work was undertaken jointly by the authors of this preliminary report. The examination began in June, 1903, and, with some interruptions, due to various causes, the field work was concluded in April, 1904. Practically every accessible mine in the district was examined in greater or less detail. Mr. L. C. Graton served as assistant throughout this time, actively participating in all branches of the work. Messrs. A. M. Rock and J. Bruce also rendered very efficient aid as draftsmen.

PRODUCTION.

Though situated close to the centers of population in Colorado and in an easily accessible region, the gold deposits of Cripple Creek were not discovered until 1891. To a great extent the lateness of the discovery was due to the extremely inconspicuous character of the vein croppings and to the equally inconspicuous appearance of the dark-brown, powdery gold set free by the oxidation of tellurides. As soon as the true character of the veins was ascertained the development of the district proceeded rapidly. In 1894, when the first survey was made, the production was a little less than $3,000,000, but the next year this amount was more than doubled, and in 1900 the maximum production of a little over $18,000,000 was attained. In 1901 and 1902 the production declined slowly, and dropped the next year to $13,000,000. The sudden decrease in 1903 was to some extent brought about by the impoverishment of several mines, but the labor troubles of that year had also much to do with it. From August, 1903, to the summer of 1904 many mines experienced more or less difficulty from this cause. It is probable, however, that the output for the current year will show a considerable increase over that of 1903.

Production of the Cripple Creek district according to the reports of the Director of the Mint.[a]

Year.	Gold.	Silver.
		Fine ounces.
1891	$449	.....
1892	583,010	.....
1893	2,010,367	5,019
1894	2,908,702	25,900
1895	6,879,137	70,448
1896	7,512,911	60,864
1897	10,139,709	57,297
1898	13,507,244	68,195
1899	15,658,254	82,520
1900	18,073,539	80,166
1901	17,261,579	90,884
1902	16,912,783	62,690
1903	12,967,338	42,210
Total	124,415,022	646,193

The total dividends can not be ascertained on account of the many individuals and small companies operating in the district. The dividends of the larger companies, it is stated, amounted to $32,752,000 to the end of 1903. In that year it is reported that $1,716,000 was paid by fourteen mines, Portland, Strong, and Stratton's Independence leading, with $360,000, $300,000, and $250,000, respectively.

MINING AND METALLURGY.

At the present time there are about 300 mines in the district, though many of these are idle and others are consolidated into larger properties. The number of shafts 1,000 feet or more in depth is about 22; of these the Lillie is the deepest, having attained 1,500 feet. Comparatively few of the mines are pumping, the district being drained by tunnels, as will be described in a following paragraph. The motive power for hoisting is ordinarily steam, electric power being used only in smaller shafts. The mining methods employed present few features of particular interest. The width stoped ranges from 3 to 50 feet or more. The stopes are sometimes filled, but are often left open after the broken rock between levels has been drawn off. Operations are facilitated by the great hardness of the rock, stopes 200 feet or more in height sometimes standing for years. To an annual production of $18,000,000 (1900) corresponded a maximum output of about 600,000 tons. The ores are not adapted to concentrating by ordinary means.

[a] The figures given in the Mint reports are considerably lower than those usually quoted in mining journals and popular descriptions of the district.

Hand sorting and washing, the latter in order to separate the fines, are the methods employed. More care is now taken than formerly, but at many places there is still room for improvement.

The district contains many large mines operated by strong companies, but the system of leasing to individuals and small companies, with royalty charges of 15 to 25 per cent of the net output, remains a conspicuous feature. At the present time the mines of the northwestern and northeastern parts of the district are only slightly productive. Among the formerly highly productive mines in this section may be mentioned the Victor, Isabella, Wild Horse, Damon, Logan, Orpha May, Pharmacist, C. O. D., Gold King, and Anchoria-Leland. The southwest quarter of the district contains the active and important El Paso, Mary McKinney, and Elkton mines, but the maximum output during the last few years has come from the southeastern portion, within which are the Portland, Gold Coin, Ajax, Strong, Golden Cycle, Vindicator, and Last Dollar mines. The Portland mine has for some time been the heaviest producer in tonnage as well as in value. Its output is from 60,000 to 90,000 tons per annum. In 1903 this mine produced $2,600,000.

The metallurgical history of the camp is interesting. Beginning with local amalgamating mills, the practice soon changed to local chlorination and cyanide plants. It was soon found, however, that better situations would be found in the valleys, and at present a very large part of the tonnage is shipped to chlorination and cyanide works at Colorado City and Florence. About a sixth of the output, comprising the higher grade ores, is sent to smelting works at Denver or Pueblo. A still smaller amount is treated in a local chlorination plant near Victor. While in former years the practice leaned more toward the cyanide process, the bulk of the ore is now treated in large chlorination mills with automatic roasters and revolving barrels. It has always been found necessary to roast all except the completely oxidized ores. At the present time there are in the district two small mills in which the cyanide process is used without previous roasting, and which are thus enabled to work ores containing as little as $5 a ton in gold. The extent of these low-grade ores is not yet fully demonstrated. Regarding the value of the ore, see page 21.

Treatment charges at the mills fluctuate somewhat, but usually range from $7 to $13 a ton, according to the tenor of the ore; in the early part of 1904 the prices were reduced, it is reported, and ranged from $5.50 to $10 per ton. Recently they have again been increased. On the whole the mining and milling expenses are very high at Cripple Creek compared with those of other localities—western Australia, for example, where similar ores and conditions prevail. Few of the large mines seem to have reduced total expenses below $16 per ton.

TOPOGRAPHY.

The mines are situated in a group of bare, rounded hills forming part of the high plateau extending southwestward from Pikes Peak, and are only about 10 miles distant from that prominent landmark. The elevations range from 9,000 to nearly 11,000 feet above sea, the highest point in the district being Trachyte Mountain (10,863 feet). Bull Hill and Bull Cliff are but slightly lower. The drainage is chiefly southward toward the Arkansas River. The district contains two important towns. Cripple Creek is situated on the northwest side of the producing area, while Victor, 3 miles distant, lies on the southwest edge of the same area. Two railroads connect the district with Colorado Springs, the Colorado Midland circling around the north side of Pikes Peak, while the Short Line descends to the valley along the picturesque eastern slope of the same mountain. The Florence and Cripple Creek Railroad runs southward to Florence in the Arkansas Valley. An excellent system of electric-car lines connects the towns with all the important mines.

GENERAL GEOLOGY.

FIRST GEOLOGICAL SURVEY OF THE DISTRICT.

When Mr. Whitman Cross made his careful study of the geology of the Cripple Creek district, ten years ago, mining had barely begun and the various hills were not, as now, perforated by deep underground workings. That his work has in general stood the test of subsequent underground exploration and continues to be highly regarded in the district is convincing proof of its high quality. Later workers, however they may modify or amplify his results, should acknowledge their debt to the pioneer who first deciphered the history of this volcanic district. The account of general geology, as given by Cross, may be very briefly summarized as follows:

The Cripple Creek hills lie near the eastern border of an elevated and much dissected plateau which slopes gently westward for 40 miles, from the southern end of the Colorado Range, dominated by Pikes Peak, to the relatively low hills connecting the Mosquito and Sangre de Cristo ranges. The prevailing rocks of this plateau are granites, gneisses, and schists. The granites inclose masses of Algonkian quartzite and are therefore post-Archean. But they are older than the only Cambrian sediments known in Colorado, and on the Cripple Creek map have been indicated as Algonkian. During Tertiary time volcanic eruptions broke through these ancient rocks at several points and piled tuffs, breccias, and lavas upon the uneven surface of the plateau. The eruptive rocks of the Cripple Creek district are the products of one of the smaller isolated volcanic centers

of this period, a center characterized by the eruption of phonolite, which does not occur elsewhere in this general region.

The most voluminous products of the Cripple Creek volcano now preserved are tuffs and breccias. They occupy a rudely elliptical area in the center of the district, about 5 miles long in a northwest-southeast direction and about 3 miles wide. According to Cross these breccias and tuffs rest in part upon an earlier flow of andesite, but mainly upon an unevenly eroded surface of the granites and schists, although along the southwest edge of the area the contact was found to be so steep as "to support the idea that the central vent or vents of the volcano were adjacent to this line." The breccia is much indurated and altered, but was thought by Cross to consist mainly of andesitic fragments, although it was recognized that fragments of phonolite are locally abundant. The most characteristic massive rock of the Cripple Creek volcano is phonolite, which was erupted at several periods and more abundantly than any other type. It occurs as dikes and masses, not only in the breccia but in the surrounding granitic rocks.

The general succession of igneous rocks, according to Cross, is as follows: The earliest rocks were andesites containing some orthoclase. Then came a series of allied phonolitic rocks, rich in alkalies and moderately rich in silica, together with some andesites. Among them are trachytic phonolite, nepheline-syenite, syenite-porphyry, phonolite, mica-andesite, and pyroxene-andesite. Phonolite was erupted at several periods. The nepheline-syenite he considered as probably younger than the trachytic phonolite. At the close were intruded a small number of narrow dikes of basic rocks, the so-called basalts, which contrast very markedly with the phonolite.

MODIFICATIONS OF EARLIER RESULTS.

In the course of the present investigation the geology of the district has been entirely remapped upon the carefully revised topographic base. The granites, gneisses, and schists have been differentiated and outlined in greater detail than was practicable in the earlier investigation. The oldest rocks in the district are muscovite- and fibrolite-schists. These are closely associated with the fine-grained granitic gneisses such as underlie most of the town of Cripple Creek. This gneiss, in the earlier report, was mapped partly as schist and partly as granite. Both gneiss and schist are cut by a reddish granite which occupies a considerable area extending from Anaconda westward beyond the limits of the area studied. This granite is well exposed along Cripple Creek in the vicinity of Mound.

A second type of granite distinguished and mapped is the coarsely porphyritic rock referred to by Cross as the Pikes Peak type of granite. This rock occupies over half of the district and is the prevailing type

along the northern, eastern, and southern borders of the area. It is well exposed on Squaw Mountain and is the granite of the El Paso, Elkton, Ajax, Portland, Independence, and Gold Coin mines. Of these two kinds of granite the Cripple Creek variety is probably the younger. The Cripple Creek granite, the gneiss, and the schist together form a wedge-shaped area projecting into the Pikes Peak granite from the west. The center of volcanic disturbance practically coincides with the point of this wedge.

The present investigation indicates some necessary modifications of the earlier report in the way of stronger emphasis on the intimate genetic relationship of the rocks. The "phonolite," "nepheline-syenite," "trachytic phonolite," "syenite-porphyry," and "andesites" of Cross are all very closely related and have been found to be in most cases connected by intermediate types. They are clearly all slightly divergent eruptive facies of one general magma characterized chemically by containing from 9 to 15 per cent of potash and soda, the soda being always somewhat higher than the potash, particularly when the comparison is made by molecular ratios. None of the massive rocks can properly be called andesite, and although it can not be affirmed that andesitic fragments are entirely absent from the usually much altered volcanic breccia, the term "andesitic breccia" does not seem applicable to this formation as a whole. It would be more accurate to describe it as a phonolitic breccia, although in places it consists chiefly of particles of the older rocks through which the Tertiary eruptives broke.

None of the massive rocks erupted from the Cripple Creek volcanic center and now preserved in the district show any evidence of having been surface flows. They are for the most part intrusive porphyries, ranging in texture, however, from the granular so-called nepheline-syenite near the town of Independence to the nearly aphanitic phonolite of the smaller dikes and sheets. Most of them will come under the designations phonolite, trachytic phonolite, trachydolerite, and alkali-syenite. The extensive underground workings show that the "nepheline-syenite" does not cut the "trachytic phonolite," but that the two rocks represent textural and, to some extent, mineralogical facies of the same mass, while the trachytic phonolite in turn may pass into phonolite. The trachytic phonolite is in some instances cut by dikes of phonolite, showing, as Cross has already pointed out, that the phonolitic intrusions were not all synchronous.

While it is undoubtedly true that much of the breccia in the northeastern part of the volcanic area rests upon a very uneven surface of granite, gneiss, and schist, the results of field work during the last season, favored by deep workings not in existence when the district was originally surveyed, have emphasized the fact that the breccia lying southwest of a general northwest-southeast line drawn through

Big Bull Mountain and Gold Hill occupies a chasm of profound depth in the fundamental rocks of the region. From the Conundrum mine on the western slope of Gold Hill to Stratton's Independence mine on the south slope of Battle Mountain the contact plunges steeply down, with dips ranging in general from 70° to vertical. In some instances the granite walls of this chasm actually overhang the breccia. It is probable that this entire southwest contact represents a part of the wall of the great pit formed by the volcanic explosions that produced the breccia. It is further probable that an arm or branch of this volcanic abyss, now filled with breccia and intrusive rocks, extends northeastward past Bull Cliff and the town of Altman.

ECONOMIC GEOLOGY.

EARLIER WORK.

To the excellent work of Mr. R. A. F. Penrose, jr., apply statements similar to those made in the discussion of the purely geological branch of the subject. Few shafts had then attained a depth of 400 feet, and most of the exposures were masked by surface oxidation. It would be surprising, in view of the facilities created by the later development of hundreds of mines, if a subsequent investigation should not bring out some slight modifications of earlier results.

EXTENT OF PRODUCTIVE TERRITORY.

There is nothing in the history of the district since 1894 warranting any extension of the bounds of the productive territory as then known. Now, as then, a circle of 3 miles radius described from the summit of Gold Hill would include all deposits of known or prospective value, while the really important mines would be embraced by a circle of about half that radius, with its center near the summit of Raven Hill. That scattered deposits of greater or less value may be found in outlying portions of the district is by no means improbable. But the close dependence of the typical Cripple Creek ores upon the main volcanic center, and the consequent remarkable compactness of the gold-bearing area, are features highly characteristic of the district and are likely always to remain so.

The greater part of the ore has undoubtedly come from the central area of breccia, particularly from that part of this area in which the breccia extends to great depth. Very productive ore bodies have been found, however, in the granitic rocks, usually within 1,000 feet of the steep contact limiting the breccia on the southwest. The important Beacon Hill mines, with ore bodies nearly three-quarters of a mile from this contact, are exceptional, and are probably genetically connected with the intrusive mass of phonolite forming the core of *the hill.*

UNDERGROUND DEVELOPMENT.

At the time of the earlier survey the deepest shafts, those of the Moose, Pharmacist, and Anna Lee mines, were down only about 400 feet, while few of the other mines were over 200 feet in depth. Many subsequently prominent mines were then mere prospects or had not been located.

The deepest shaft at present is the Lillie, which is over 1,500 feet deep, although the Stratton's Independence shaft, 1,400 feet deep, has the lowest sump in the district. The American Eagle shaft is nearly as deep as the Lillie, while there are about twenty other shafts over 1,000 feet in depth, and at least 100 shafts deeper than the deepest workings existing in 1894. As regards absolute elevations, the Gold Hill shafts are scarcely down to a level of 9,000 feet above sea; the Elkton, El Paso, and Lillie shafts descend to 8,750 feet; Stratton's Independence reaches the lowest level at 8,450 feet; while the Gold Coin shaft, at 8,550 feet, is of interest from the fact that the deepest ore shoot in the district is now being stoped from its twelfth level.

The amount of drifting and crosscutting accomplished since the earlier survey is more than commensurate with the increased number and depth of the shafts, and the district is further intersected in various directions and at different levels by two long tunnels run for drainage purposes and by a dozen or more extensive adits, many of which have their portals in the granitic rocks and extend well into the central part of the breccia area.

BRIEF REVIEW OF THE MINES.

The productive district, as stated above, is practically covered by the area of a circle 3½ miles in diameter. The center of this circle would be located halfway between Raven Hill and Bull Hill, and the towns of Cripple Creek, Victor, and Cameron would be situated on its periphery. A very few mines—notably the Galena and the Fluorine—and many prospects lie outside of this area.

The culminating points of the district are found in a ridge of high and bare hills that extends in a northwest-southeast direction and divides the waters flowing into Cripple Creek and Wilson Creek on the southwest from those joining Spring Creek and Grassy Creek on the north. From northwest to southeast the following hills mark this divide: Mineral Hill, Carbonate Hill, and Tenderfoot Hill, north or northeast of Cripple Creek; Globe Hill, Ironclad Hill, and Bull Hill, the latter being near the center of the district and equidistant from Cripple Creek and Victor; the ridge is continued by Bull Cliff and Big Bull Mountain, the latter, really outside of the productive area, being the highest point in this dividing range of hills. Its elevation is 10,826 feet. Three long spurs project to the southwest from

the dividing range separating the deep trenches of Cripple Creek, Squaw Gulch, Arequa Gulch, and Wilson Creek; the first, called Gold Hill, rises directly east of Cripple Creek; the second is Raven Hill, being continued to the southwest by the lower spur of Guyot and Beacon hills; the third is Battle Mountain, continued by the almost equally high salient of Squaw Mountain.

The important mines are situated in this region of sharply accentuated topography. As has been several times emphasized, the volcanic area practically coincides with the hills and ridges just described and is surrounded on all sides by granitic rocks.

Globe and Ironclad hills and Gold and Raven hills consist chiefly of heavy masses of breccia, and were scenes of great activity during the early years of the district. Near Poverty Gulch, just northeast of Cripple Creek, is the Abe Lincoln, not a large mine, but still actively worked with satisfactory results. Higher up are the Gold King, with dividend records of $150,000, and the C. O. D., with a reported production of $600,000 and dividends of $150,000. Both were idle in 1904 and have attained their eighth or ninth levels.

On the summit of Globe Hill are the Stratton properties of Plymouth Rock and Globe mines, in which extensive low-grade mineralization without many sharply defined veins seems to be the rule. Adjoining is the property of the Homestake Company, including the Ironclad mine, where direct cyaniding of oxidized surface ores is now carried on in a mill erected on the property.

Gold Hill is crowned by the Anchoria-Leland mine, with a production of over $1,000,000 and dividends of $198,000. The shaft is 1,100 feet deep. The adjoining Moon-Anchor has paid dividends of $261,000, and the Half Moon (Matoa G. M. Co.) has a gross production of $650,000 to its credit, but is reported to have paid only a small amount in dividends. None of these mines is being worked at present, except on a small scale by lessees.

On the western slope is the Midget mine, actively worked at present, with a depth of 800 feet, a total production of $662,000, and dividends of $195,000. The Conundrum, in the same vicinity, is likewise worked with good results to a depth of 600 feet. The Midget, like the mines described above, follows a vein in breccia, while the Conundrum is mining on a "basalt" dike in granite, close to the contact of the breccia.

In the deep gulch between Gold Hill and Raven Hill are situated the Anaconda, Doctor-Jack Pot, and Mary McKinney mines, all working on sheeted zones forming lodes in the breccia. The Anaconda produced about $1,000,000, chiefly from upper levels, and is now idle. The Mary McKinney is one of the most successful mines worked at present in the district. Its depth is 600 feet. The Doctor-Jack Pot has $4,000,000 to its credit and likewise a handsome dividend record.

The shaft is only 700 feet deep, water having until now prohibited deeper sinking.

The breccia-granite contact is found on Guyot Hill a short distance south of the Mary McKinney. The extreme spur of Raven Hill, called Beacon Hill, is formed of an intrusion of phonolite in granite, and about this outlying volcanic center cluster a group of veins of great production and promise. On the eastern side of the hill are located the Prince Albert, Gold Dollar, and others, not active producers at present, while on the western side lie the El Paso, C. K. & N., and Old Gold mines, with their narrow but extremely rich fissure veins in granite, now actively and successfully worked.

A great number of smaller mines have been worked on veins cutting the breccia of Raven Hill. The famous Elkton mine is situated in the deep hollow between Raven Hill and Battle Mountain. It has been working on an exceptionally long vein, partly contained in breccia, partly in granite, and generally following a "basalt" dike. The production approaches $6,000,000, and the depth attained is about 900 feet, excessive water having formed a serious obstacle to deeper sinking. Dividends amount to $1,200,000. The Moose mine, situated higher up on the slope of Raven Hill, had a good ore shoot, from which $500,000 was obtained.

Continuing northwest, we soon attain the summit of Bull Hill, which affords a magnificent panorama, not only of the whole camp, but of a large part of the State of Colorado. Toward the east, and 5,000 feet lower, spread the great plains at the foot of the Rocky Mountains; westward the Sangre de Cristo, Collegiate, and Mosquito ranges—a snowy and jagged line of ramparts—define the distant horizon.

A multitude of small mines occupy the southwestern slope of Bull Hill. On the northwestern side an area of brecciated granite appears among the volcanic rocks, and in this formation is situated the Wild Horse mine. This lode, which has been worked to a depth of 1,250 feet, has produced over $1,000,000, but is now operated only by lessees. A number of smaller producers may be found on the northern slope, toward Cameron, among them the Damon, Jerry Johnson, W. P. H., and Pinnacle.

Those who have followed this description on a map will have noticed that the mines are chiefly situated on the periphery of a circular area, the central part of which, comprising the upper part of Squaw Gulch, has thus far yielded very little. Few strong veins have been met with in this part of the breccia, but, on the other hand, the developments in depth are not extensive.

On the east and southeast side of Bull Hill begins that most important belt of lodes which extends southward to Victor and includes the richest group of producers in the camp. A characteristic feature of

this belt is the intrusion into the breccia of thick masses of trachytic phonolite and syenitic rocks.

With few exceptions the veins of this belt strike north-northwest. We may begin the description with the system of linked veins, 3,000 feet long, covered by the Isabella and Victor mines. The last-named mine, on the southern end of the system, is situated just below the western slope of Bull Cliff. It has been worked to a depth of over 1,000 feet, has produced about $2,200,000, and has paid dividends amounting to $1,150,000. The Isabella has attained a depth of 1,127 feet, produced $3,200,000, and paid dividends of $600,000. Both mines lost their pay shoot in depth.

The small but rich cross veins of the Empire State, Burns, Pharmacist, and Zenobia connect this vein system with that of the Stratton mines on Bull Hill. South of the Burns begins the great Vindicator vein system, traced southeasterly for a mile through the Findley, Hull City, Vindicator, Lillie, and Golden Cycle mines. The Hull City and the Lillie have each produced over $1,000,000, the Vindicator and Golden Cycle over $2,000,000 each, all with corresponding dividend records. The Lillie is deepest, having attained 1,500 feet. Next in depth is the Vindicator, 1,200 feet. All of them, except the Lillie, are still actively worked. In the whole system water has been and is still a source of trouble. The deepest mine evidently drains all the others in this vicinity.

The Stratton properties on Bull Hill, with the Logan, Orpha May, and Pikes Peak veins, on which maximum depths of 1,200 and 1,500 feet have been attained, are now worked only to a slight extent, whereas in the early days of the camp they were highly productive.

This vein system is continued southward in the Last Dollar mine, now working at a depth of 1,270 feet. The production exceeds $1,000,000. South of the Last Dollar the veins enter the Modoc ground, a mine worked for a long time and with gratifying success. The Blue Bird, an old-time producer, is situated a short distance west of the Last Dollar.

South of the Modoc is the Battle Mountain vein system, crossing from the granite into the breccia, with general northerly or north-northwesterly directions, and distinguished by heavy production and ore bodies of imposing size. None of the veins are of great length, and the whole system extends scarcely a mile along the strike of the veins. The veins can not be directly connected with others already described, though, in its general trend, the system heads toward the Dexter, Blue Bird, and Moose veins.

Beginning on the southwestern side, we first come to the Gold Coin mine, the veins of which are in granite; one of them is successfully worked at present at a depth of 1,200 feet. The total production approaches $6,000,000; the dividends paid exceed $1,000,000. North

of the Gold Coin is the Ajax, working partly in veins, partly in large, irregular ore bodies in the granite. The total production is very considerable. The depth attained is 1,200 feet.

Between this and the Portland vein system, almost within the town of Victor, are the Granite, Dillon, and Dead Pine veins. They are worked at present at depths of from 800 to 1,000 feet.

The Portland vein system begins on the south at the Strong mine, now worked at a maximum depth of 900 feet, on a vein in granite that follows a "basalt" dike, which is in places accompanied by a phonolite dike. The mine is an unusually regular and profitable producer, the total dividends since 1892 amounting to $2,500,000.

The veins of Stratton's Independence run about parallel to those of the Strong, a few hundred feet eastward. They extend from the granite into the breccia, following for some distance a phonolite dike. The production of this mine amounts to over $11,000,000, with a dividend record of $4,000,000 since 1899. At present the company is leasing the various levels to tributers. From the two properties last described the vein systems continue into the Portland mine, but in the northern part of that great property are replaced by another and still richer aggregate of veins, the Captain system. The Portland is, beyond question, the most prominent mine of the Cripple Creek district. Its total production from 1894 to the end of 1903 amounted to $18,000,000, derived from 466,000 tons of ore (both in round figures), from which $4,600,000 has been paid in dividends, the remainder going to acquirement of territory, extensive milling and mining plants, and operating expenses.

Outside mining properties.—The area outside of the principal volcanic area contains very few productive properties, but it is by no means barren. A great deal of money has been spent here, usually with unsatisfactory results. Although there are many properties of merit and although much honest effort has been made in this part of the district, it has long been the favorite camping ground of concerns more or less lacking in stability.

The granite hills west and south of the city of Cripple Creek contain few prospects; phonolite dikes occur in places, but usually show little value. Along Gold Run and Arequa Gulch prospects with a little ore have been found, down to the junction with Cripple Creek, and even at isolated places below this locality. Grouse Mountain, with its phonolite cap, shows many prospects from which occasional good assays have been obtained, but neither here nor on Straub and Brind mountains has anything of permanent value been developed thus far. It is claimed that ore bodies of low grade, containing a few dollars per ton, exist.

The breccia caps of Mineral, Carbonate, and Tenderfoot hills are dotted with prospect dumps, and even shafts several hundred feet

deep. Nothing of permanent value is recorded from Mineral Hill, though fairly productive placers have been worked at its southwestern base, almost in the town of Cripple Creek.

On Carbonate Hill the Elkhorn has been a small producer; on Tenderfoot Hill the Friday, Hoosier, Black Diamond, and Mollie Kathleen contribute their parts to the production. Two miles north-northwest of Cripple Creek is the Galena mine, the vein of which follows, for a part of its course, a phonolite dike in granite and has a small output to its credit. About the same distance north of the city is the small volcanic center of Copper and Rhyolite mountains. At the former the Fluorine mine has produced $160,000, and low-grade ore is now being cyanided. Prospects are found on Rhyolite Mountain, and in fact all over the flat granite country between it and Trachyte Mountain. The Lincoln mine, near Gillette, and several other prospects farther south, along a belt of phonolite dikes, have produced a little ore. It is claimed that there are low-grade veins on both sides of Bernard Creek, northwest of Gillette, in a region of granite with occasional dikes and masses of phonolite. Trachyte Mountain, southeast of Gillette, is covered by phonolite, and a little ore is occasionally found in veins at its southern foot. Some work has also been done on Cow Mountain, about 4 miles northeast of Bull Hill.

The eastern margin of the central volcanic area, east of Victor Pass and extending southward across Big Bull Mountain to Brind Mountain, has thus far failed to produce anything of importance, though well covered by prospects. A survey of these outlying parts of the district serves to emphasize strongly the remarkable concentration of deposits within the narrow limits of the central volcanic area.

CHARACTER OF THE ORES.

The characteristic feature of the Cripple Creek ores is the occurrence of the gold in combination with tellurium, chiefly as calaverite, but partly also as the more argentiferous sylvanite,[a] and probably to a minor extent as other gold, silver, and lead tellurides. The tellurides are frequently associated with auriferous and highly argentiferous tetrahedrite, with molybdenite, and occasionally with stibnite. While these minerals have not yet been closely studied, preliminary examination indicates that their contents in gold are due to an intimate mechanical mixture of tellurides. Pyrite, while widely disseminated through the country rock and of common occurrence in the fissures, is rarely sufficiently auriferous to constitute ore. Such of the pyritic ores as have been tested reveal the presence of tellurium, indicating that the ore is a mixture of pyrite and gold-silver tellurides. Galena and

[a] Calaverite (AuAg) Te_2: tellurium, 57.4 per cent; gold, 39.5 per cent; silver, 3.1 per cent. Sylvanite (AuAg) Te_2: tellurium, 62.1 per cent; gold, 24.5 per cent; silver, 13.4 per cent.

sphalerite occur in small quantities in many of the mines, but rarely contain enough of the precious metals to form ore. Native gold appears to be absent from the telluride ores, except as it may be set free by the oxidation of these tellurides.

The usual gangue minerals of the ores are quartz, fluorite, and dolomite. Roscoelite and rhodochrosite are also found in places. Celestite, or sulphate of strontium, while never present in large amount, frequently occurs as little acicular crystals in the quartz vugs of the lodes. Calcite occurs interstitially in much of the breccia near the ore bodies, but is rarely found in distinct crystalline form with the ore minerals. Secondary potassium feldspar is common in the ores; it is especially abundant in the ores inclosed in granite, particularly those in the Pikes Peak type. This feldspar has the composition of orthoclase or microcline, and is formed by the recrystallization of the original potassic feldspar contained in the rocks. In the granitic ores of the Stratton's Independence, Portland, Ajax, and Elkton mines, this secondary feldspar is the principal gangue mineral.

Oxidized ores, while still worked in many properties, are of relatively less importance than when Penrose described the district. They contain the characteristic dull gold, often in pseudomorphous skeletons, resulting from the oxidation of the tellurides, associated with tellurite (tellurium dioxide), emmonsite or durdenite (both hydrated ferric tellurites), and probably other oxidized compounds of tellurium and iron. These minerals occur in association with kaolin, alunite, and ferruginous clays. The deep workings of the present day show that kaolin is always connected with oxidation, and is not a product of the original mineralization of the district, as was supposed by Penrose.

The Cripple Creek ores, as a rule, contain very little silver, the average proportion being about 1 ounce of silver to 10 ounces of gold. In the Portland and Stratton's Independence mines the proportion is very much less, the silver from the Portland in 1901 amounting to only 2.4 ounces for each 100 ounces of gold. In the Blue Bird, Doctor-Jack Pot, Conundrum, Pointer, and other mines containing notable amounts of tetrahedrite or galena, the proportion of silver rises considerably above the average.

The average value of the Cripple Creek ores lies probably between $30 and $40 per ton. In some of the larger mines the average value sinks to about $25 per ton. From a lower economic limit of about $12 per ton the values of individual shipments swing through a wide range up to ores carrying $3,000 or $4,000, or even $8,000, per ton. Occasionally smaller amounts—one or two tons—have yielded as much as $50,000 per ton.

STRUCTURAL CHARACTER OF DEPOSITS.

With few exceptions the ore bodies, of whatever shape, are causally connected with fissures, and most of them constitute fissure veins of various types. The fissure system of the district appears to radiate from a point near the northern limit of the volcanic area. In the eastern part the prevailing directions are northwest or north-northwest, gradually changing to a northerly strike in the southern portion and to predominant north-northeast or northeast courses in the western side of the district.

Individual veins are rarely over half a mile in length, but linked-vein systems often extend for a mile in the same direction. The dip is generally very steep. The movement along these fissure planes appears in all cases to have been very slight. The fissures charged with ore are sometimes simple veins with one fracture plane; much more commonly, however, they are composite veins or lodes which consist of several closely spaced and frequently linked fissures, all more or less ore bearing. A better expression for this structural type as it appears in Cripple Creek is the term "sheeted zone."

TYPES OF DEPOSITS.

The most important types of auriferous ore bodies occurring in the district are:

1. Tabular in form and strictly following simple fissures or sheeted zones. A subtype comprises lodes in which the sheeted zone follows "basalt" or phonolite dikes.

2. Irregular bodies adjacent to fissures and formed by replacement and recrystallization of the country rock—usually granite.

These types are not always sharply distinct, but may be connected by deposits of intermediate character.

All the ore bodies, of whatever type, exhibit certain common features which serve to distinguish the deposits of Cripple Creek from those of most other mining districts. In the first place, the actual openings in the rocks available for the deposition of ore are, as a rule, remarkably narrow. In the second place, the amount of material carried in the mineralizing solutions and deposited as gangue and ore minerals was comparatively small. In consequence of these two conditions, the district contains no such massive veins, solidly filled with quartz or other vein minerals, as are characteristic of the San Juan region in Colorado or the Mother Lode region in California. Even the small fissures of the Cripple Creek district are rarely completely filled, but exhibit a characteristic open or vuggy structure. Where the fractures are of unusual width, or where the rocks are extensively shattered, as in the Midget and Moose mines, the small volume of available vein matter is particularly noticeable. The walls of such fractures and the

fragments of the shattered rock are usually merely coated with a thin deposit of quartz, fluorite, and other minerals. As the rich tellurides were usually among the minerals last to form, and are particularly abundant on the walls of the vugs, it is probable that had quartz, fluorite, or other gangue minerals been more abundantly deposited the ores would have been of much lower grade.

Sheeted veins.—The mineralized sheeted zones constitute the most characteristic deposits of the district and occur in practically all the rocks, although particularly common in breccia. They consist of a varying number of narrow, approximately parallel fissures, together composing a sheeted zone that may range from a fraction of a foot to 50 or 60 feet in width. Such uncommonly wide zones of fissuring, however, can usually be resolved into two or more sheeted zones lying so close together that the whole constitutes for practical purposes a single ore body, as in the Captain vein system of the Portland mine. Usually the sheeted zones are from 2 to 10 feet in width. In other cases the fissures may be very numerous, the rock for a foot or more in width being divided into thin parallel slabs, while on each side of this medial portion the fissures become farther and farther apart as the lode grades into the normal country rock of the vicinity. In still other cases there may be two main fissures, 3 or 4 feet apart, accompanied by more or less irregular fracturing of the intervening and adjacent rock. As a rule the fissures are mere cracks, showing no brecciation, slickensiding, or other evidence of tangential movement of the walls. Usually the tellurides are exclusively confined to the narrow fissures and cracks, and do not, in this type of deposit, in any sense constitute a replacement of the country rock. The rocks in the vicinity of the fissures are partly replaced by dolomite, pyrite, and a little fluorite; the telluride ores, however, do not share this propensity, but coat the open fissures, associated with a little quartz and fluorite. Replacement by tellurides does occur in two other types of deposits, to be described later; but as regards the simple veins and sheeted zones, it will be necessary to modify the results of Penrose by restricting the metasomatic rôle of the tellurides. In the oxidized parts of the veins, such as were almost exclusively available for observation when Penrose visited the district, these relations can seldom be clearly ascertained, and would easily lead one to overemphasize replacement as a feature of vein formation. The fissures are not, in general, planes of faulting. Appreciable movement has undoubtedly occurred in some instances, but the displacement probably rarely exceeded 1 or 2 feet.

Although found most abundantly in the breccia or trachytic phonolite, sheeted zones and single fissures are often well developed in the granite, as in the El Paso, C. K. & N., and Gold Coin mines. While in some of these lodes the ore minerals are as plainly confined to the fis-

sures as in the breccia, in other cases the ore to some extent permeates the granite alongside the fissure, this constituting a deposit intermediate in nature between types 1 and 2. They also frequently follow phonolite dikes, the general tendency of these dikes to develop a platy parting parallel to their walls being particularly favorable to the production of a well-defined sheeted zone when the direction of fissuring happens to coincide with that of the dike.

The metasomatic alteration accompanying these sheeted zones is surprisingly slight, and consists of a partial replacement of the breccia, phonolite, trachytic phonolite, or "basalt" by dolomite and pyrite accompanied by a small amount of sericite and a little secondary potash feldspar. But even in the most altered rock the newly formed minerals rarely form more than a small percentage of the rock mass. The alteration in granite exhibits a somewhat different phase, described in a subsequent paragraph.

Not all the sheeted zones carry ore, nor is the ore of a productive sheeted zone necessarily coextensive with the fissuring. The ore occurs in pay shoots up to 2,000 feet in length and 1,000 feet in depth, but usually very much smaller than is indicated by these limits. The boundary between the ore and the barren portions of the lode can be determined, as a rule, only by assays. No single factor that can account for the localization of the ore in these pay shoots has been discovered. In some mines the pay shoots occur where the lode is intersected by cross fissures; in other mines no such relation exists. In some mines ore occurs where the fissures pass through phonolite dikes; in other mines the lode, elsewhere productive, becomes barren when it enters phonolite; while in still others the presence of the phonolite has had no apparent influence upon ore deposition. It thus appears that the occurrence of two or more favorable factors is necessary to determine the position of a pay shoot in a lode. The discovery of these factors is one of the unsolved problems connected with the Cripple Creek district.

Replacement deposits in granite.—The replacement deposits in granite all occur in close proximity to the contact with the breccia, and are well developed in the Elkton (Thompson), Ajax, Independence, and Portland mines. Although these bodies of ore are related to fissures and occur particularly where several fissures intersect, or where they meet a dike, the ore is not confined to the actual fractures. The rock in the vicinity of these fissures is often extensively altered. The change from altered to unaltered rock, while never perfectly sharp, is often fairly abrupt and may take place within a distance of a few feet. The most obvious characteristic of the metamorphosed rock is a porous texture and a change of the reddish color of the normal granite to grayish or greenish tints. Closer examination shows that, while the porphyritic aggregates of pink microcline, so prominent in the Pikes

Peak type of granite, may remain unaltered, the rest of the rock, consisting originally of microcline, oligoclase, quartz, and biotite, may be completely recrystallized as a porous, vuggy aggregate of secondary orthoclase (valencianite), quartz, fluorite, pyrite, calaverite or sylvanite, and, in exceptional cases, sphalerite and galena. The ore minerals are partly inclosed in the other secondary minerals, but occur most abundantly with little projecting crystals of fluorite, quartz, and valencianite on the walls of the irregular pores so characteristic of the altered rock. The biotite of the original granite yields most readily to alteration, and, in rock otherwise almost entirely unaltered, may be changed to an aggregate of fluorite, quartz, and ore minerals. Some of the ore of the Ajax mine exhibits well this initial stage of alteration. With further alteration the original quartz and oligoclase of the granite are attacked. The quartz, originally in large homogeneous and irregular grains, recrystallizes as aggregates. Secondary orthoclase or valencianite forms often in clear, sharply idiomorphic crystals, which either project into open cavities or form aggregates with the secondary quartz. In many cases, however, the secondary valencianite results from the recrystallization of the older microcline practically in place. The two generations are sometimes distinguishable by the greater clearness and more or less idiomorphic form of the younger mineral and the absence of the characteristic microcline twinning. But it is often impossible to determine the line between feldspar which, from its association with quartz and fluorite, is clearly secondary and the original microcline of the granite. Occasionally a little calcite may be detected in the altered granite, but this is rare. The original apatite and zircon of the granite are not, so far as observed, affected by the alteration described.

While the replacement deposits in granite are important because of their size and the readiness with which the ore may be mined free from waste, the ore itself is usually of lower grade than that formed in the fissures of the sheeted zones.

Mineralized "basalt" dikes.—The ore bodies formed by the mineralization of basic dikes are in some ways closely related to the sheeted zones already described. Like the phonolite dikes, the "basalt" exhibits a pronounced tendency to split into thin sheets parallel with the dike walls. Normally, the minute fissures so formed are filled with veinlets of calcite and contain no ore. When, however, a zone of fissuring coincides with the dike the latter may be traversed by veinlets of quartz and fluorite carrying sylvanite or calaverite, while the body of the dike may be impregnated with pyrite. Such ore differs from that of the usual sheeted zones in breccia or phonolite in that the tellurides are not so clearly confined to the actual fissures, but appear to some extent to permeate the rock with the pyrite. The richest portion of the ore, however, undoubtedly occurs in the small veinlets in the dike,

and usually near one or both walls where the fissuring is best developed. The occurrence of rich ore bodies in basic dikes in the Portland (Anna Lee), Moose, Elkton, Conundrum, Pinto, and other mines has tended to exaggerate the importance of these dikes in general, and some have even supposed a genetic relation to exist between them and the mineralization of the district.[a] Such an hypothesis, however, loses sight of the vast amount of profitless work that has been expended in the district in driving on the usually unproductive basaltic dikes, and the very small proportion of the known ore bodies that can be shown to have any connection whatever with these intrusions. That the basaltic dikes are not always readily mineralized even when accompanied by fissuring is shown in the interesting case of the Strong mine, where the ore occurs as mineralized granite on each side of the dike, while the latter is barren.

DEPTH OF OXIDIZED ZONE.

At a few points, as in the Abe Lincoln and El Paso mines, tellurides are found almost at the surface. It is much more common, however, to find an upper zone, from 200 to 400 feet deep, in which free gold prevails and which gradually changes to the zone of pure telluride ores. As may be expected from the varying surface form and conditions of drainage, there is great range in the depth attained by oxidation. Partial oxidation extends in many mines to a depth of over 1,000 feet, especially along the often more or less open fissures. In the Wild Horse mine the zone of complete oxidation reaches a depth of 1,100 feet and then suddenly ends. In the Isabella mine partial oxidation attained at least 1,200 feet, and the same applies to the Gold Coin mine in Victor, although telluride ores prevail at that depth as well as in many levels above. The question is chiefly one of depth of ground water and of facilities for circulation of oxygen. Further data bearing upon this problem may be found on page 31.

RELATIONS OF ORE BODIES TO DEPTH.

It is well known that the payable ores in auriferous lodes are rarely equally distributed in the lode, but form tabular bodies of more or less regular outline. The projections of these ore bodies on the plane of the lode often appear as elongated areas with greater vertical than horizontal extent. The ore bodies or shoots of Cripple Creek show great similarity to those of other gold-bearing veins; their limit in depth is usually as well defined as their extent in a horizontal direction.

Of sixty pay shoots of Cripple Creek mines plotted together for

[a] Stevens, E. A., Basaltic zones as guides to ore deposits in the Cripple Creek district: Trans. Am. Inst. Min. Eng., vol. 33, 1903, p. 686.

purposes of comparison, over thirty extended from the surface to a depth of less than 500 feet. The maximum individual production of these is less than $1,000,000. Near six of these ore bodies further exploration developed new shoots below the old ones, but usually of smaller extent. In practically all thirty cases the development work had been carried down a few hundred feet below the last ore of the surface shoot. The form of these smaller shoots is often equidimensional; in a few cases the horizontal extent is greater than the vertical, or the shoot is wholly irregular; in many cases the shoot pitches steeply northward on the plane of the vein and the ratio of vertical to horizontal extent is 2:1 or 3:1.

In eight of the sixty cases the shoot extended from the surface to a depth of 1,000 feet, or a little more, and ended. Further development to about 1,500 feet failed to find new shoots of any importance, though small pockets were often discovered. In six of these eight cases the ratio of vertical to horizontal extent varies from 3:1 to 5:1, and the shoots usually pitch northward at angles of 60° to nearly 90° from the horizontal. In the remaining two cases the shoots have about the same horizontal as vertical extent. The maximum horizontal length is 1,300 feet, while 400 is much more common. In two of the sixty cases the pay shoot is 1,500 to 2,000 feet long, maximum depths of 600 and 1,000 feet having been attained and the bottom level being still in ore. In thirteen of the sixty cases the shoot began over 200 feet below the surface; in eight of these the bottom of the shoot has been reached, while in five the lowest level is still in ore. Steeply dipping, irregular elongated forms prevail. Many of this group of thirteen represent veins parallel and close to those on which pay shoots outcropping at the surface were found.

These statements will give an idea of the form of the shoots. Of course, in the case of shoots reaching the surface, a certain part has probably been removed by erosion. Judging from the shoots which distinctly began below the surface, the normal form of the ore bodies is elongated, vertical, or pitching sharply northward, the ratio of vertical to horizontal extension varying from 1½:1 to 5:1. Some of these shoots are, however, of about equal dimensions, vertically and horizontally, while in a few the horizontal dimension is the greater.

Of the known ore bodies, as few exceed 1,000 feet in length, so very few exceed 1,000 feet in depth or extend more than 1,000 feet from the surface. Speaking broadly, explorations below that limit have not proved very satisfactory. Drawing the lines a little closer, it may be said that in proportion to the amount of exploration the upper 700 or 800 feet have yielded more than the interval from that limit to the lowest levels reached—about 1,500 feet. It must not be overlooked, however, that four or five mines still have good ore bodies at a depth

of 1,200 to 1,400 feet from the surface. The developments of the next year or two will probably give a safer basis for generalization.

Roughly speaking, the above-mentioned distribution holds good for any elevation within the district. In other words, the principal productive zone everywhere occupies the space from the surface down to about 1,000 feet below it, and its lower limit thus forms a curved surface approximately parallel to the surface of the ground.

It is probable that the minimum depth of rock removed from the district by erosion amounts to 1,000 feet in the central part and to 400 or 500 feet about the periphery. The shape and number of the ore bodies formerly existing in this eroded zone can be only conjectured. It is probable that the veins were formed shortly after the close of igneous activity, while the volcano yet possessed a much greater height than at present. The absence of hot waters and the depth of oxidation attained indicate that vein formation at Cripple Creek is by no means a recent phenomenon.

The general features of the vertical distribution of the known ore bodies recorded above have of late years received more or less recognition, and there has been a decided tendency to attribute them to a process of secondary enrichment effected by waters moving generally downward from the surface. It has been supposed [a] that such waters have carried down a part of the auriferous contents of those portions of the lodes now removed by erosion and have enriched originally lean pyritic ores by the secondary deposition of gold and silver tellurides and argentiferous tetrahedrite, with associated gangue minerals.

It is clear that the hypothesis in question is suggested by the distribution of known pay shoots. The question arises, How far does the distribution of known pay shoots represent the distribution of all the pay shoots in the district? In other words, How far has exploration been impartial in revealing ore bodies near the surface and at depths greater than 1,000 feet?

It requires but little examination to make clear the fact that ore bodies within 1,000 feet of the surface are far more likely to be discovered than those at greater depth. While shafts have been sunk for a few hundred feet without any indication of ore and have ultimately been developed into productive mines, such a procedure is considered bold prospecting, and few well-informed mining men would seriously contemplate sinking a shaft over 1,000 feet in depth solely on the expectation of finding possible ore bodies below that depth. Most of the large mines in the district have started upon some indication of ore near the surface and have grown by the subsequent discovery of other lodes and ore bodies in the course of their underground development. As few individual ore bodies persist for more than 1,000 feet in depth, by

[a] Bancroft, Geo. J., Eng. and Min. Jour., vol. 74, 1902, pp. 752-753, and vol. 76, 1903, pp. 111-112. Finch, J. W., Proc. Colorado Sci. Soc., vol. 7, 1904, pp. 193-252.

far the greater part of the underground prospecting is at less depths, there being usually little inducement to go deeper, unless, as in the case of the Gold Coin and Portland mines, lodes are discovered in which the ore, beginning several hundred feet below the surface, extends deeper than the pay shoot upon which the mine was originally opened. Thus deep prospecting is usually confined to the vicinity of the larger and more persistent pay shoots which have been followed down from near the surface. Underground water has also proved a most serious obstacle to deep prospecting, few properties being able to develop below the 1,000-foot zone unless there is abundant and high-grade ore in sight.

It may thus be concluded, without necessarily advocating promiscuous exploration below the 1,000-foot zone, that any ore bodies existing below that depth are far less likely to be discovered than those above, where from the surface to depths of several hundred feet the rocks of the district are riddled with shafts, drifts, crosscuts, and adits. It is exceedingly difficult, however, to determine, even approximately, the relative importance of this factor in the problem. It is probably safe to assume that the chances of discovering a given ore body within the 1,000-foot zone are at least ten times those of discovering an ore body below that zone, and the ratio may be very much greater. It is probably true that there was originally more ore within the 1,000-foot zone than there is in a corresponding zone below, but this disparity is not necessarily anything like so great as is indicated by the vertical distribution of known pay shoots.

Another important line of inquiry bearing upon the relations of the ore bodies to depth is concerned with the question of the relative size and abundance of the fissures near the surface and at greater depth. It has been shown that all the ore bodies are intimately connected with fissures. If such fissures are generally smaller and less abundant below the 1,000-foot zone than they are within it, obviously there is introduced a factor which diminishes the supposed importance of secondary enrichment by affording an anterior and physical explanation for the decrease of ore with increase of depth.

Detailed examination of practically all the accessible mines in the Cripple Creek district has led to the conclusion that the fissures, which ordinarily are narrow and often appear as mere cracks, do become less abundant and less conspicuous as greater depth is attained. No mine exhibits this feature better than the Stratton's Independence, in which the very complex systems of productive fissures on the fifth and higher levels contrast most strikingly with the few, insignificant, and unproductive fractures visible on the fourteenth level. In less degree the same feature is shown in many others of the deep mines, but the rule is not without some very marked exceptions.

The dependence of the ore zone on the surface would then merely express the depth to which fissuring extended in a conical volcanic mountain.

We have thus two factors of importance to account for the scarcity of ore shoots below the 1,000-foot level—first, difficulties of development and exploration, and second, the disappearance of fissures in depth. They do not seem to be sufficient, however, and it is believed that a third factor, as yet undiscovered, exists, and that it is related to the chemistry of the actual ore deposition.

In those districts where so-called secondary sulphide enrichment is known to have taken place the ore minerals exhibit in general an orderly sequence, both in relative abundance and in kind, from those characteristic of the most highly enriched ore near the zone of oxidation to those constituting the original, lean, and unaltered ore. The secondary minerals produced are such as can result from rearrangement and concentration of elements present in different combinations in the primary ores. At certain points within this range of alteration it is possible to detect direct mineralogical evidence of the change of one mineral to another, effected by solutions moving downward from the zone of oxidation. In most cases the secondarily enriched ores bear a recognizable relation to the lower limit of oxidation.

Careful study of the Cripple Creek ore deposits has failed to discover that the hypothesis of secondary enrichment is supported by crucial evidence of the kind just indicated. The minerals are not arranged in any discoverable definite sequence, nor does the present investigation find much to support the view that the rich telluride ores, as a rule, pass with increasing depth into low-grade pyritic ores. Frequently such ore as occurs below a depth of 1,000 feet is precisely the same in character as ore found within 100 feet of the surface. Tetrahedrite, which has been regarded by some, without definite proof, as a secondary mineral, occurs sporadically throughout the district and at all depths reached by present workings. The richest ore does not uniformly occur immediately below the oxidized ore. There is, in fact, little indication of enrichment in the oxidized zone such as is so often found in gold-quartz veins of the normal type. Frequently the fresh telluride ore is extremely rich, and high-grade pockets occur impartially in oxidized and fresh portions of the veins. Neither would it be correct to say that there is a gradual decrease in the value of ore in depth. It is quantity, not value, which decreases.

While it is certain that pyrite, and possibly other minerals, has formed at more than one period during the mineralization of the district, and while it is equally clear that in general the rich tellurides were the last of the ore minerals to be deposited, there is apparently no evidence that any one of these minerals has been formed by enriching solutions at the expense of primary minerals. So far as definite

conclusion is warranted in an investigation as yet incomplete, it appears that the unoxidized ore deposits of the Cripple Creek district represent the product of one general period of mineralization and that they have not been appreciably modified by secondary enrichment during the subsequent erosion of the region.

UNDERGROUND WATER.

The conditions of underground waters are interesting and somewhat unusual. A dry climate and a heavy percentage of run-off minimize the annual additions to the underground supply. Nevertheless, the ground-water level is not unusually deep, and large quantities of water are encountered in all the mines below that level. The original water surface of the district in the volcanic rocks stood at elevations of 9,400 to 9,700 feet, or 100 to 600 feet below the surface of the ground. At first pumping was commenced by individual mines, but it was soon found that the radius of drainage had unusual length—that is, that one mine would drain others situated at a distance. Drainage tunnels were then undertaken, and the Chicago and Cripple Creek, the Ophelia, the Standard, and lately the El Paso tunnels were driven, each of which practically accomplished the drainage of a large part of the district almost down to its own level, thus showing that the ground water is limited in quantity and is more of the nature of a local reservoir than a "subterranean sea."

The plug of volcanic rocks which fills the throat of the old volcano is rudely circular, with a diameter of 3 miles. This mass is extremely porous, and is, moreover, cut in many directions by partly filled fissures and sheeted zones, so that water can circulate within it with comparative freedom in several directions. It retains this character down to the greatest depth yet reached. On the other hand, the surrounding granite is relatively impermeable and is less traversed by open fissures. No doubt it contains ground water down to a depth of 2,000 feet or more, but in very much smaller quantity, and the circulation of this water must be extremely slow. This is clearly shown by the fact that the water in the breccia is not drained by Cripple Creek and Arequa Gulch below the level of the points where they leave the volcanic area. Thus the volcanic plug resembles a water-soaked sponge inserted in a hole cut in an impermeable substance. The drainage of the mines is thereby greatly facilitated, as it is not necessary to extend the tapping tunnels to each mine.

The El Paso tunnel, completed in the winter of 1903–4, has an elevation of 8,790 feet at the portal. Within a short time it effectually drained not only the Beacon Hill mines but also the Gold Hill mines, and its influence extended even to the Last Dollar and the Elkton mines. But the foregoing statement in relation to draining the dis-

trict must be so modified as to exclude a certain part on the eastern side, comprising the mines about Independence on the east side of Bull Hill and those on Battle Mountain and in the town of Victor, in which the effect of the El Paso tunnel is slight. The Findley, Hull City, Vindicator, and Golden Cycle mines about the town of Independence seem to occupy a separate drainage basin, probably divided from the main area by masses of relatively impermeable rock.

The Portland, Stratton's Independence, and the other mines near Victor occupy another drainage basin. Of these the Gold Coin and the Stratton's Independence have shafts below the level of the El Paso tunnel, and their pumps have probably drained the surrounding territory to a considerable extent. The influence of the drainage tunnel on the Portland mine is a question upon which opinions differ.

The subject of the drainage of the Cripple Creek mines has been actively studied in late years, and valuable contributions to the subject have been made by Mr. Victor G. Hills and others, who have shown that the water can be tapped, without prohibitive expense, down to an elevation of 7,500 feet, or 1,300 feet below the El Paso tunnel; for this depth a tunnel 3½ miles long would be needed. On account of the great porosity of the rocks it is not probable that the next thousand feet below the El Paso tunnel level will show any great diminution in the amount of water stored in the rocks.

SUBTERRANEAN GASES.

During the earlier years of Cripple Creek no unusual amount of mine gases was observed, but, as the shafts and workings deepened, several properties began to experience much annoyance and even serious interference with work, often in spite of vigorous measures for ventilation. These gases appear to issue chiefly from the breccia, especially where it is of porous and loose texture, but they sometimes flow from partly open vein fissures in such quantity that a light held up to the fissures is immediately extinguished. Thus far the mines on Battle Mountain and those of the Golden Cycle, Vindicator, and Isabella groups have suffered no inconvenience, but most of the mines west of this line have had more or less trouble with this subtle and insidious enemy. At least one mine has been forced to close down entirely, and several others are often obliged to abandon work for days. Sometimes the amount of gas issuing is small, and ordinary ventilation will carry it away; again it may issue in large volumes and practically fill the mine for some time. In other mines the gas persistently hangs at certain places, forming barriers which can be passed only with difficulty. The outflow of gas is unquestionably related to barometric fluctuations, though it is usually locally reported

to be influenced by the direction of the wind. The investigations concerning this subject are not yet concluded. It may be said, however, that a sudden lowering of the barometer seems to be the most important factor. Upon such a fall the gas issues in great volumes, but decreases when the barometer remains steadily low for several days. The gas is often very heavy, filling lower parts of drifts and winzes like water, and cases are reported in which it has actually been bailed from a shaft. Its temperature is somewhat higher than that prevailing in the mine under normal conditions.

It has practically no smell or taste, but small quantities of it easily produce effects of suffocation. Miners working in places where this gas is mixed with the air soon experience various forms of physical distress, and several fatal accidents have been caused by men entering drifts and winzes filled with it.

The characteristics of the gas seemed to point to carbon dioxide, and it is generally so termed. Preliminary determinations of carbon dioxide by a portable apparatus yielded percentages which seemed far too small in comparison with the effects of the gas examined, and led to the belief that some other substance was present. Samples were then collected and analyzed. The analyses showed the gas to be a mixture of nitrogen with about 20 per cent carbon dioxide and a small amount of oxygen.

The occurrence of these exhalations over a large part of the ore-bearing area is of much interest. They certainly increase in quantity with depth, and it is to be feared that in some cases they may seriously affect mining operations. The evil has proved very difficult to cope with. Ventilation alone has rarely proved efficient, and the only practicable remedial measures appear to be cementation of drifts at particularly bad places and working the mine under air lock at a pressure slightly exceeding the normal.

The origin of these gases can not reasonably be sought in any such explanation as the oxidizing of sulphides and accompanying absorption of oxygen. We believe that they represent the last exhalations from the throat of the extinct Cripple Creek volcano.

FUTURE OF THE DISTRICT.

To predict the future yield of any mining district is no easy task; the conditions under which most ores are deposited are as yet too imperfectly understood, and the deposits themselves are usually too erratic in form and distribution, to give certitude to such predictions, even when these are based upon a careful study of the history and present condition of a district. Nevertheless, it is part of the duty of the geologists who have officially investigated the Cripple Creek district to interpret to the best of their ability the bearing of ascertained

facts upon future mining development. For such a forecast of the future moderate probability is all that can be claimed.

As has been pointed out in the preceding pages, the largest known ore bodies of the district are apparantly confined within a zone which extends from the surface to a depth of 1,000 feet. In general, explorations below that depth have been much less satisfactory, as regards quantity of ore, than explorations above. It is certainly true that some large ore bodies as yet show no sign of depletion in depth, and that some good pay shoots have been found at a depth of 1,400 to 1,500 feet. On the other hand, the number of ore shoots that have been exhausted with increase in depth is considerable.

It is probable that the ore bodies, known or unknown, occurring below the 1,000-foot zone are neither so large nor so abundant as those nearer the surface. The discovery and exploitation of these deeper ore bodies is, moreover, beset with increasing difficulties, chief among which is the problem of dealing with the underground water. For these reasons it is unlikely that the zone between the 1,000-foot and 2,000-foot levels will yield as much as the zone between the surface and the 1,000-foot level, but the possibility is not denied that some strong fissures may carry payable ore to far greater depths than those yet attained.

As regards the zone above the 1,000-foot or 1,500-foot level, it is well to bear in mind that it still contains much ore, both as parts of known ore shoots and as yet undiscovered ore bodies. It is certain that many of these undeveloped ore bodies will be mined in the near future and that this zone will contribute the most important part of the production.

It is probable that the production of the district, while exhibiting fluctuations, will on the whole slowly decline. New ore bodies will undoubtedly be discovered from time to time, and individual mines may be as profitable in the future as they have been in the past, or even more profitable. An increased output may be expected to follow each successful step in deep drainage. But existing conditions indicate that if the maximum production of $18,000,000, in 1900, is to be surpassed the increase will be due to the ore bodies encountered in the upper zone.

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B, Descriptive Geology, 62

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

THE FLUORSPAR DEPOSITS OF SOUTHERN ILLINOIS

BY

H. FOSTER BAIN

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GOVERN

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., July 16, 1904.

SIR: I have the honor to transmit herewith the manuscript of a paper entitled "Fluorspar Deposits of Southern Illinois," by H. Foster Bain, and to recommend that it be published as a bulletin.

This paper embodies the results obtained in a detailed study of the fluorspar deposits of this important district, the study having been undertaken in connection with the investigation of the lead and zinc deposits of the Mississippi Valley region. The area covered is at present the most important producer of fluorspar in the United States.

Very respectfully,

C. W. HAYES,
Geologist in Charge of Geology.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

THE FLUORSPAR DEPOSITS OF SOUTHERN ILLINOIS.

By H. Foster Bain.

INTRODUCTION.

LOCATION.

The fluorspar mines which are the subject of this report are in Pope and Hardin counties, in the extreme southern portion of Illinois. The principal mines are near Rosiclare, Elizabethtown, and Cave in Rock, small towns on the Ohio River, in Hardin County. An impor-

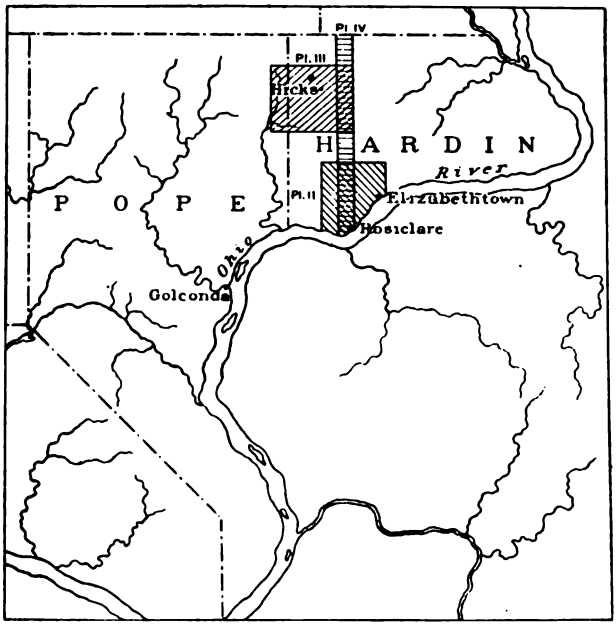

Fig. 1.—Sketch showing areas covered by detailed maps.

tant group of prospects is located in the northwest part of Hardin County and northeast part of Pope County, and there are minor occurrences at various other points in these counties and also in Saline and Johnson counties. The area forms the northern part of the Kentucky-Illinois district. Its outline and general situation are

indicated on the accompanying map, Pl. I. In fig. 1 are indicated the particular areas surveyed in detail in the preparation of this report.

HISTORY OF DEVELOPMENT.

Attention seems to have been first attracted to the Kentucky-Illinois district by the occurrence of the brilliant colored fluorite. In early American geologic literature there are numerous references [a] to this fluorspar, or "fluate of lime," as it was then called. It was usually noted as coming from Shawneetown, Ill., since that was the nearest town of any size. The galena which occurs associated with the fluorite was probably noticed very early in the nineteenth century, but it was not until some years after the settlement of the country that any serious attempt was made to mine it. The first important mining venture seems to have been that of a company headed by President Andrew Jackson, which undertook development near the site of the present Columbia mines, in Crittenden County, Ky., in 1835. In Illinois the first mining was at Rosiclare in 1842. Lead was mined and smelted at various points in the district previous to the civil war, though it seems never to have been remunerative in a large way. Various observers speak of the mining as having been stopped, or as being carried on in only a small way from 1851 [b] to 1876.[c] As late, however, as 1884 competent observers considered some at least of the properties worthy of development for lead alone,[d] and there is even now a small output of lead.

In Illinois fluorspar seems to have been first discovered in place in 1839, when it was encountered with galena in sinking a well on the Anderson farm, now the property of the Fairview Fluorspar Company. In 1841 a second well not far from the first also encountered the lode, but no attempt seems to have ever been made to exploit either of these finds. In 1842 Mr. William Pell discovered spar and galena somewhere near the site of the present Rosiclare mine, and Marshall and White undertook its development. From that time on mining appears to have been carried on more or less continuously in this vicinity, at first under the direction of certain well-known Mis-

[a] Am. Jour. Sci., 1st ser., vol. 1, 1818, pp. 52–53; vol. 2, 1820, p. 176; vol. 3, 1821, p. 243. Schoolcraft, H. R., A View of the Lead Mines of Missouri, 1819, p. 191. Cleaveland, Parker, Mineralogy, 1822, p. 202. Brush, J. G., Am. Jour. Sci., 2d ser., vol. 14, 1852, p. 112.

[b] Norwood, J. G., Geol. Survey Illinois, vol. 1, 1866, p. 367. Owen, D. D., Geol. Survey Kentucky, vol. 1, 1856, p. 87. Whitney, J. D., Rept. Geol. Survey upper Mississippi lead region, 1862, p. 205.

[c] Norwood, C. J., Geol. Survey Kentucky, vol. 1, new ser., 1876, p. 493.

[d] Ellers, Anton, and Raymond, R. W., Manuscript report on the property of the Mineral City Mining and Smelting Company, Hardin County, Ill.

souri operators, Messrs. Valle, Anson, and others, and in recent years with the ownership in local and eastern hands.

Shipments of fluorspar began apparently in the early seventies, and since 1880 have been regularly reported. In 1891, when the district was visited by Mr. S. F. Emmons, large bodies of spar had been developed, though, as seems to have been usually true since the beginning of mining in this region, only one or two mines were actually shipping.

Zinc was early noted [a] in the district and from time to time small trial shipments were made. With the rise in the price of zinc in 1899, a period of active prospecting for zinc ore began. The discovery of the Old Jim mine in Kentucky stimulated the search and the whole district was gone over with considerable care by local prospectors. Very few important deposits of zinc ore were found, but the size and purity of the fluorspar deposits became for the first time adequately appreciated. There has since been an active and intelligent campaign to widen the market for spar and to increase its production. Incidentally some lead and zinc is being found and mined, though so far no important bodies of either have been developed in the Illinois portion of the district.

PREVIOUS GEOLOGIC WORK.

The Kentucky-Illinois district has been visited by but few geologists. The official reports of the States include brief reports [b] upon the district. Aside from these the most important paper is one by Mr. S. F. Emmons,[c] which was based upon a brief visit to the Rosiclare mines made in 1891. Mr. J. S. Diller [d] has published a description, with analysis, of the mica-peridotite forming the Flannery dike in Kentucky, based upon specimens collected by Mr. E. O. Ulrich. Brief notes upon the mining industry have been published by Mr. W. E. Burk,[e] and a description of the Old Jim mine has been given in the Engineering and Mining Journal.[f] Short notes on development of the district have been given in connection with the statistics of production annually published by the United States Geological Survey in the Mineral Resources, and notes on the fluorite as a mineral have appeared in other parts of these volumes.

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[a] Owen, D. D., op. cit., p. 87.

[b] Kentucky: Owen, D. D., Geol. Survey Kentucky, vol. 1, pp. 87–88. Norwood, C. J., Geol. Survey Kentucky, new ser., vol. 1, 1876, pp. 449–493. Illinois: Worthen, A. H., Engelmann, Henry, and Norwood, J. G., Geol. Hardin County, Geol. Survey Illinois, vol. 1, 1866, pp. 350–375. Engelmann, Henry, Massac and Pope counties, Geol. Survey Illinois, vol. 1, 1866, pp. 428–495.

[c] Fluorspar deposits of southern Illinois: Trans. Am. Inst. Min. Eng., vol. 21, 1893, pp. 31–53.

[d] Am. Jour. Sci., 3d ser., vol. 44, 1892, pp. 288–289.

[e] Mineral Industry, 1901, vol. 9, pp. 292–295.

[f] Eng. and Min. Jour., vol. 74, 1902, pp. 413–414.

SCOPE OF THIS REPORT.

The present paper is essentially a preliminary statement of results based upon work done in 1903 in the Illinois portion of the Kentucky-Illinois district. In this work the writer had the field assistance of Mr. A. F. Crider, and the benefit of both field and office consultation with Mr. E. O. Ulrich, whose thorough familiarity with the Kentucky mines and the stratigraphy of the entire region contributed greatly to the work. Mr. Albert Johannsen has furnished petrographic notes, which are incorporated in the general description of the dike rocks. The report is intended to supplement the fuller discussion given by Mr. Ulrich and Mr. W. S. Tangier Smith of the district in general and the Kentucky mines in particular.[a] Brief statements concerning both portions of the district have already been published.[b]

PHYSIOGRAPHY.

GENERAL RELATIONS.

The Kentucky-Illinois fluorspar district lies well toward the middle of the Mississippi Valley, that great level-floored basin which occupies the continental interior of the United States. The district is somewhat nearer the Appalachian than the Rocky Mountain border of the valley and about midway between the Great Lakes and the Gulf of Mexico. The Mississippi Valley, though a monotonous plain when contrasted with its surroundings, has been differentiated into a number of physiographic provinces, which stand in somewhat marked contrast with one another. Of these, three—the Allegheny Plateaus, the Gulf Plains, and the Ozark Plateau—meet within this district, while the Prairie Plains join it on the north.

The Allegheny Plateaus are represented by the Interior Lowland, as defined by Mr. C. W. Hayes.[c] This occupies much of the mining district in Kentucky and includes the upland between the Ohio River and Karbers Ridge, in Pope and Hardin counties, Ill. The Gulf Plains include the southern portion of Pope and the adjacent part of Massac County, in Illinois, and that portion of Kentucky which lies west of the Tennessee River. The more exact limits are shown, covered with Tertiary and Cretaceous deposits, on the accompanying general geologic map of the district (Pl. I). The Ozark Plateau is represented by a long, narrow ridge of highland stretching across southern Illinois from about Grand Tower, on the Mississippi, to Shawneetown, on the Ohio. This plateau is represented in Pope and Hardin

[a] Prof. Paper U. S. Geol. Survey No. 36, in press.

[b] Ulrich and Smith, Bull. U. S. Geol. Survey No. 213, 1903, pp. 205–213. Bain, Bull. U. S. Geol. Survey No. 225, 1904, pp. 505–511.

[c] Hayes, C. W., Southern Appalachians: Mon. Nat. Geog. Soc., vol. 1, 1895, p. 310.

LEGEND

Cretaceous and Tertiary

Pennsylvanian (Coal Measures)

Mississippian (Limestones on bottom)

Devonian (Black slate)

Dikes

GENERALIZED GEOLOGIC MAP
OF THE
KENTUCKY ILLINOIS FLUORSPAR DISTRICT

Scale

15 10 5 0 5 miles

1904

counties by Karbers Ridge, and its northern limit is defined by the South Fork of Saline River and certain tributaries of the Big Muddy.

The Interior Lowland has in this area a general altitude of 500 feet. It merges with the Gulf Plains along a sinuous line marking the overlap of Tertiary deposits upon an erosion plain beveling older rocks. It abuts sharply against the Ozark Plateau, which rises abruptly 200 to 250 feet above it, and which also overlooks the Prairie Plains to the north, which lies here at a general altitude of about 450 feet. Below the Interior Lowland and the Gulf Plains the Ohio and other rivers of the district have cut important channels to a general controlling base of 300 feet.

TOPOGRAPHY.

Karbers Ridge.—Crossing the northern portion of Pope and Hardin counties is a belt of high land presenting an abrupt escarpment face to the south. It is limited on the south approximately by the southern boundary of the Mansfield sandstone (see Pl. I). The escarpment rises 150 to 200 feet above the rolling plain at its base. The ridge itself is narrow and in Pope County reaches out in long, finger-like minor ridges between the southward-flowing streams. The main ridge rises to 700 or 750 feet above sea level, and is the most notable topographic feature of southern Illinois. As already indicated, it extends westward to the Mississippi, beyond which it is represented in the Ozark Plateau. To the east it becomes less and less distinct until lost in the uplands of western Kentucky.

In Hardin County it has a general east-west course and is excellently displayed. In T. 3 N., R. 8 E., and T. 3 N., R. 9 E., it is very sharply defined, the southward-fronting escarpment forming a great frowning wall. In Pope County the trend of the escarpment becomes more southwesterly. About 5 miles northwest of Golconda it is crossed by the road to Raum, the ridge here forming a narrow projecting point of high land between the branches of Lusk and Little Grand Pierre creeks. It rises here to nearly 800[a] feet above sea, approximately 230 feet above the general upland at its base and 500 feet above the river at Golconda. Farther west it has not been especially studied.

On the north side the ridge in Gallatin County presents an even more striking front. From its base stretches the great plain of central Illinois, underlain by the soft beds of the Coal Measures. Farther west the northern boundary is not so well defined.

Various names have been applied to this ridge at different points. There has been as yet no adequate physiographic study of the region as a whole, and for the present no attempt need be made to define and

[a] All elevations are based on barometer determinations and are approximate only.

name the entire ridge. For convenience that portion developed in Pope and Hardin counties will be called by the local name "Karbers Ridge," a name also applied to a small village at the base of its south front.

Upland plain.—At a lower level and extending southward from Karbers Ridge to the Ohio River is a rolling, broken plain sloping gently from about 600 feet elevation at the north to 500 feet at the south. While somewhat irregular in detail, it is in general a markedly level plain. The high Shetlerville Hills rise somewhat above it, but aside from them all the country south of Karbers Ridge in Illinois is at or below the level of this plain. In Kentucky there are several hills which rise above it, and in both States the rivers and their tributaries have reduced considerable areas to a lower level. Along the north side of the Ohio such a lower plain is locally developed between Elizabethtown and Cave in Rock. Here a strip approximately parallel to the river and 2 miles wide has been reduced to an altitude of about 440 to 460 feet. North of this strip the country rises very abruptly to 550 or 600 feet, after which the even upland plain is preserved, except for the interruptions due to river valleys, to the foot of Karbers Ridge. North of Golconda there is a distinct bench at about 480 feet above sea, while above that, at 550 to 575 feet, is the general upland plain.

The upland plain is developed upon various sorts of rocks. Limestones, sandstones, and shales outcrop at various points within its limits, and all have been cut down to a common level. Locally the individual formations influence the topography, as northeast of Elizabethtown, where the St. Louis limestone underlies the lower plain mentioned, and as in the case of the Shetlerville Hills, twin peaks, conspicuous from every point upon the upland, which are largely composed of the hard sandstone and conglomerate of the Mansfield. The plain is a true peneplain and marks an ancient base-level of erosion. It was formed at a time when the surface of the earth was undisturbed for so long a time that the streams broadened their valleys until the hills between were almost entirely cut away. The time at which this occurred is approximately fixed by the fact that in southern Pope County the plain passes very gradually beneath the gravels and sands which are believed to be of Tertiary age. In southern Illinois also this plain marks the northwestern limit of the Interior Lowland, whose age has been fixed as Tertiary at a number of points.[a]

River valleys.—Into the upland plain the rivers have cut their valleys. For the most part these are rather narrow and sharp walled. The Ohio, the master stream of the area, has a low-water level of 290 feet from Golconda to Elizabethtown. It flows between high rock

[a] Hayes, loc. cit.

walls for the greater part of its course. At 345 feet there is at several points a wide development of bottom land, as at Elizabethtown, Rosiclare, and near the mouth of Lusk Creek at Golconda. From Bay City the low land extends west in a broad belt, known as the Bay Bottoms, to Cache River, in Johnson County. In periods of flood an independent connection between the Ohio and Mississippi rivers is established by this route. At Rosiclare the bottom is likewise subject to overflow. The Ohio makes the impression of being very imperfectly adjusted to its valley. The great Bay Bottoms cut directly through the upland, but are traversed by only insignificant streams, while at various points along the Ohio the valley seems none too large for the stream. The arrangement of tributaries is also erratic. Near the mouth of Grand Pierre Creek are tributaries which head within a few feet of the Ohio, but flow northward and by a roundabout way into the minor stream. There are no topographic maps of the region and no good drainage maps, so that it is unsafe to make many generalizations. It seems clear, however, that the streams are poorly adjusted and that they show evidence of superposition. Their courses were for the most part determined when the present upland was a lowland, and with its uplift they have cut directly downward without much adjustment through hard and soft rocks alike. The most important tributaries of the Ohio—Big Creek, Grand Pierre Creek, and Lusk Creek—have cut back across the upland until their headwaters are at work upon the south slope of Karbers Ridge. At several places the tributaries of these streams on the south and those of the Saline River on the north have cut entirely through the ridge, forming passes or gaps. Packers Gap, near the headwaters of Grand Pierre Creek, is one of the best known.

GEOLOGY.

GENERAL STATEMENT.

Both igneous and sedimentary rocks occur in this district. The former are represented in a number of dikes found near the Ohio River and are all, so far as known, of the same general class of rocks. The sedimentary formations represent four different systems—Devonian, Carboniferous, Tertiary, and Quaternary. The Devonian outcrops are confined to a limited area in northern Hardin County; the Tertiary gravels are found only in southern Pope County; the Carboniferous occupies the larger part of the territory, while the loess loam of the Quaternary extends as a thin mantle over the whole. The Carboniferous rocks consist for the most part of formations belonging to the Mississippian series, the Mansfield sandstone alone representing the Pennsylvanian. In the

division and classification of the Carboniferous, the scheme used by Mr. Ulrich in his discussion of the adjacent Kentucky district has been adopted in its entirety, with the exception that, as a matter of practical convenience in preliminary mapping, the dividing line between the St. Louis and the Tullahoma is drawn at a slightly higher horizon than the one recognized by him, and the Spergen Hill discriminated by him between the St. Louis and the Ste. Genevieve was not recognized in the course of this work. Mr. Ulrich considers the Birdsville and Tribune formations the equivalent of Kaskaskia as originally defined, and these with the Cypress and the Ste. Genevieve as making up the Chester. In the earlier work of Engelmann and Worthen[a] the lines were somewhat differently drawn, but for reasons which Mr. Ulrich has elsewhere discussed it is impracticable to follow them exactly. A general tabular arrangement of the formations is presented below.

Table of formations, southern Illinois.

System.	Formation.	Character.
Quaternary		Loess loam.
Tertiary	Lafayette (?)	Gravels.
Carboniferous	Mansfield	Sandstone and conglomerate.
	Birdsville	Sandstone, shale, and thin limestones.
	Tribune	Limestones.
	Cypress	Heavy-bedded sandstone.
	Ste. Genevieve	Oolitic limestones.
	St. Louis	Limestones and chert.
	Tullahoma	Chert and limestone.
Devonian	Ohio	Black shale.

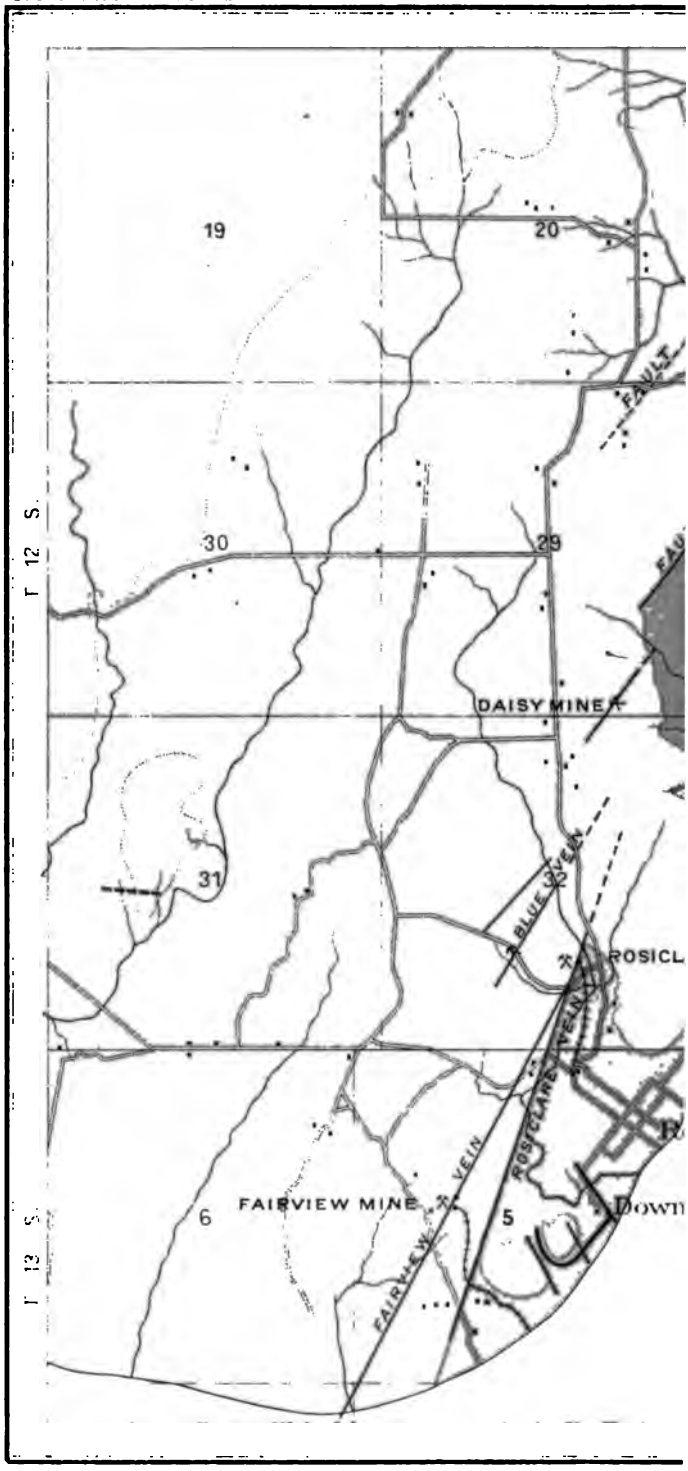
DESCRIPTION OF SEDIMENTARY FORMATIONS.

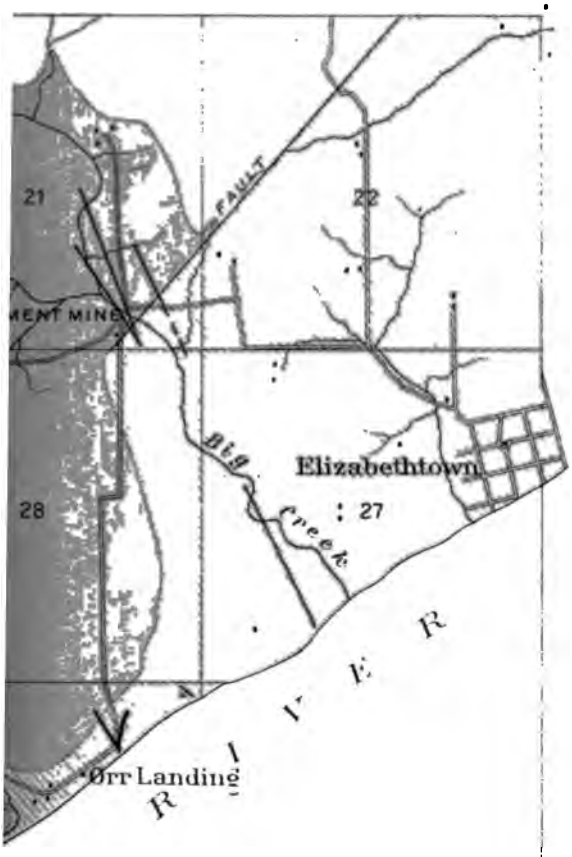
DEVONIAN ROCKS.

OHIO SHALE.

Character.—The Ohio shale as developed in this area is a black, fissile shale or slate. It splits in very thin sheets parallel to the original bedding and is very uniform in character. The only exception to this statement is that at the top a thin bed was observed which Mr. Ulrich considers the equivalent of a similar bed forming the top of the formation in middle Tennessee.[b] In it there are small, rounded

[a] Geol. Illinois, vol. 1, pp. 76–83, 348–495.
[b] Geologic Atlas U. S., folio 95, U. S. Geol. Survey, 1903, p. 2.


19
20
FAULT
30
29
DAISY MINE
31
BLUE VEIN
ROSICL
ROSECLARE VEIN
FAIRVIEW VEIN
6
FAIRVIEW MINE
5
T. 12 S.
T. 13 S.



LEGEND

POST CARBONIFEROUS

Lamprophyre
(dykes and sheets)

CARBONIFEROUS

Mansfield sandstone
(sandstone and conglomerate)

Birdsville, Tribune, and Cypress sandstone
(sandstone and shale; thin limestone near middle)

Ste. Genevieve limestone
(oolitic limestone)

St. Louis limestone
(cherty limestone)

Veins

Faults

Mines

Strike and dip

GEOLOGIC MAP OF THE ROSICLARE DISTRICT ILLINOIS

BY
H. FOSTER BAIN, ASSISTED BY
E. O. ULRICH AND A. F. CRIDER

Scale
½ ¼ 0 ½ mile

1904

JULIUS BIEN & CO. LITH. N.Y.

pebbles of black material, probably phosphate of lime. There is also a certain amount of a green, flaky material, probably glauconite. This bed is very thin and was observed at only one point.

Thickness.—The total thickness of the formation is unknown, as its bottom is not exposed and there are no drill holes passing through it. A careful estimate was made by Mr. Ulrich and the writer; at least 50 feet are exposed, and probably 100 feet or more are present. It is difficult to make an exact estimate owing to imperfect exposures and variable dips.

Distribution.—No exposures of the shale are known except in the vicinity of Hicks, in Hardin County. The shale here outcrops over two areas, as indicated on Pl. III. It is found here in the bottom of streams, but is covered by younger rocks of the hills. It occurs in a series of exposures showing dips outward from a common center and indicating that it is brought to the surface in a low dome. The general relations are indicated on the special map of the Hicks area and in the cross section from Rosiclare to Karbers Ridge (Pl. IV).

Name.—In the older publications this shale was referred to merely as the Devonian black shale. It is believed to be the equivalent of the Chattanooga shale of Tennessee, the New Albany shale of Indiana, and the Ohio shale of Ohio. The latter, being the oldest geographic name used for it, is adopted in the present discussion.

CARBONIFEROUS ROCKS.

TULLAHOMA FORMATION.

Character.—The Tullahoma, as developed in Hardin County, consists for the most part of flint or chert. It includes some shale and a subordinate amount of nonmagnesian limestone, but the latter is rarely exposed, as it has usually been dissolved, and merely a gentle talus slope of flint fragments remains. Mr. Ulrich, in discussing the formation as developed along Hicks Branch, recognizes the following divisions:

> In the basal 50 feet the shales predominate in the ratio of about 2 to 1. In the next 50 feet the layers of shale and chert constitute about equal proportions of the mass, while an occasional layer of limestone is intercalated. In the third 50 feet the shale decreases to little or nothing, while the chert and limestone bands alternate and are about equally important. In the fourth 50 feet shales are practically absent, the limestone has become somewhat heavier, though irregularly bedded, and the chert is proportionately less abundant. At the top there are 25 feet or more of slightly cherty, light-colored, massive or laminated limestone, containing fenestellid Bryozoa.

In this report the line between the Tullahoma and the St. Louis is drawn at the top of these beds or at the lowest ledge marked by the common presence of the easily recognized coral *Lonsdalia* (*Litho-*

strotion). Mr. Ulrich would class the upper 25 feet of strata as above described with the succeeding formation rather than with the Tullahoma.

Thickness.—Exact measurements of the thickness of the formation are not available, but checked estimates, based upon dip measurements and barometer observations, place it at 200 to 225 feet.

Distribution and relations.—The Tullahoma outcrops in northwestern Hardin County in a belt around the dome of Ohio shale near Hicks. Its area of outcrop is limited in turn by a similar belt of St. Louis limestone, the next succeeding formation. So far as known the formation does not come to the surface elsewhere in these counties, though it is quite possible that small areas are exposed in the faulted region east of that represented on the Hicks special map. In Kentucky, Mr. Ulrich has recognized the formation near Smithland and near Princeton. It rests with slight uncomformity upon the Devonian shale below. The relations to the St. Louis are less clear, and it can only be stated that there is no obvious unconformity in the Hicks area.

Name and correlation.—The name Tullahoma is derived from a locality in Tennessee, where it was applied by Safford in 1900 to the equivalent beds. The formation represents early Mississippian time, including probably that within which the Kinderhook, Burlington, and Keokuk formations were deposited along the Mississippi. It shows only general faunal relationships to these formations, and it is impracticable to make detailed correlations with them.

ST. LOUIS LIMESTONE.

Character.—The St. Louis limestone is for the most part a fine-grained, dark-colored rock, breaking with a sharp conchoidal fracture. It is moderately thin bedded and apparently nonmagnesian. It is characterized by the presence of abundant chert nodules, which are irregularly rounded and are most marked along bedding planes. They frequently show a distinct concentric structure, and individual nodules 3 to 4 inches in diameter are very prominent and characteristic on weathered or fractured surfaces.

The St. Louis limestone is apparently exceptionally soluble, and its areas of outcrop are marked by numerous sink holes, which often contain ponds of water. The irregular surface and large number of ponds remind one strongly of a drift-covered surface.

Thickness.—A thickness of 105 feet of limestone is exposed at Jacks Point on the Ohio, near Elizabeth. The beds have a low dip, which, if maintained, would give a total of several hundred feet as the thickness exposed along the Ohio, but of this there is no certainty. Mr.

Ulrich estimates the thickness of the formation in this district at 300 to 400 feet.

Distribution and relations.—The St. Louis outcrops over a considerable area in Hardin County. In the vicinity of Hicks it surrounds the belt of Tullahoma, and is itself surrounded by the Ste. Genevieve. To the southeast of Hicks it is cut off by a fault (Pl. IV), which brings it into juxtaposition with the Birdsville and the Mansfield sandstones. To the east and beyond the limits of the detailed maps the relations are less certainly known, but faulting seems to have largely determined the boundary lines of its areas of outcrop.

The limestone covers a considerable area adjacent to the Ohio River and extending from Cave in Rock to Rosiclare. It extends from the river back to Lead Hill, a maximum distance of 3 miles, and its north boundary is in part at least determined by a fault plane. At Elizabethtown the limestone is well displayed in the river bank and may be seen immediately in front of the Rose Hotel. It is exposed at intervals down to the small stream entering the river a quarter of a mile below Orr's landing, where the Ste. Genevieve limestone makes its appearance. The relations of the two are not altogether clear. The rocks along the stream dip toward it on either side, and the presence of barite, fluorspar, and quartz seems to indicate a certain amount of fracturing of the rock. There is, however, no certain evidence of faulting, and the relations may be those of simple conformity. Between this point and Big Creek Bridge (Pl. II) there are practically no outcrops. At this point the relations of the St. Louis to the Ste. Genevieve are almost certainly those of faulting, such as quite certainly are the relations of the St. Louis and the Cypress sandstone.

Name and correlation.—St. Louis is a well-known name, long applied to the beds here mapped under it. Engelmann, in his early work in this region, correlated these beds with those exposed and studied at St. Louis, and there are no reasons for questioning his conclusions.

STE. GENEVIEVE LIMESTONE.

Character and thickness.—The Ste. Genevieve limestone is in many instances lithologically similar to both the St. Louis limestone below and the Tribune above. It is fine grained, medium bedded, and nonmagnesian. Its most common distinguishing characteristic is the presence of massive oolitic beds, which may easily be distinguished from the occasional beds of oolite in the other formations by their thickness, massiveness, and light color. The formation has also an abundant and characteristic fauna which is readily recognized. *Amplexus geniculatus* and *Platycrinus huntsvilli* may be mentioned among the most widespread of its characteristic fossils. Mr. Ulrich

recognizes three members within the formation. They may be described as below:

Generalized section Ste. Genevieve limestone, southern Illinois.

	Thickness in feet.
Ohara member. Limestone, fine grained, thin bedded, in part shaly and always associated with shale	30–107
Rosiclare member. Calciferous sandstone; in weathered exposures showing much sand and usually marked cross-bedding; in unweathered surfaces predominantly calcareous material and easily overlooked	1–25
Fredonia member. Mainly oolitic limestones, white and light blue, interbedded with crinoidal, crystalline, and fine-grained limestones	113
Total	144–245

While the whole of the formation is fossiliferous, the Ohara member is particularly so, the shaly bands being crowded with fossils. One of these bands, occurring usually about 30 feet above the Rosiclare sandstone and being about 8 feet thick, forms a horizon easily recognized and hence of considerable importance in stratigraphic work. From it at Shetlerville the following fossils, as determined by Mr. Ulrich, were obtained:

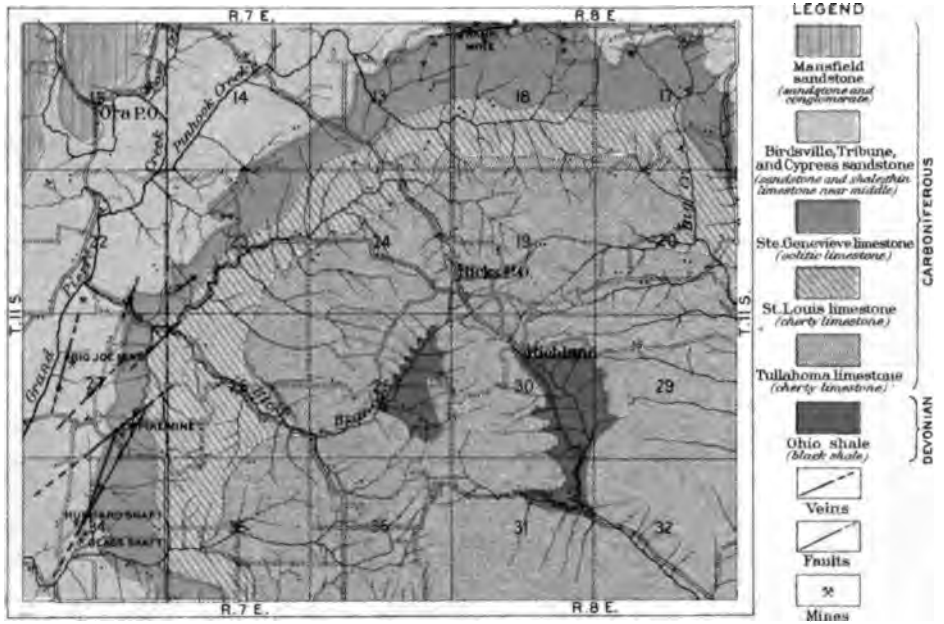
Zaphrentis pellæensis.
Amplexus geniculatus.
Pentremites florealis.
Spirifer leidyi.
Spiriferina norwoodi.
Spiriferina transversa.
Cleiothyris sublamellosa.
Cleiothyris hirsuta.
Seminula trinuclea.
Dielasma formosa.
Dielasma turgidum.

Distribution.—The Ste. Genevieve limestone is very widely distributed in both Pope and Hardin counties. It is shown on the accompanying maps (Pls. II and III), both surrounding the St. Louis limestone near Hicks and outcropping between it and the Cypress sandstone in the Rosiclare area. In addition, it occurs both east and north of Cave in Rock, near Shetlerville, Eichorn, and at various other points which will be more particularly noted in describing the various mines. Its significance in the present discussion arises from the fact that the important ore bodies so far found have been in most cases closely associated with this limestone.

Name and correlation.—In the work of Engelmann and Worthen the Ste. Genevieve limestone was not discriminated from the St. Louis and the general group to which the name Chester was applied. The Fredonia member seems to have been considered to belong with the St. Louis, while the Rosiclare and Ohara members were sometimes included with the overlying beds and sometimes not.[a]

These discrepancies came mainly from the fact that faulting was not recognized as important in interpreting the stratigraphy of the

[a] See sections, p. 78 and p. 397, Geol. Survey Illinois, vol. 1, 1866.



GEOLOGIC MAP OF THE HICKS DISTRICT

BY H. FOSTER BAIN

ASSISTED BY A. F. CRIDER AND E. O. ULRICH

Scale

1 mile ½ 0 1 mile

1904

JULIUS BIEN & CO. LITH. N.Y.

district. Mr. Ulrich recognizes these beds as the equivalents of those to which Shumard originally gave the name Ste. Genevieve in Missouri, and that name is accordingly applied to them here.

Princeton limestone is a name for the beds which has obtained a certain amount of local use, but which is considered synonymous with Ste. Genevieve. On account, principally, of the affinities of its fauna, Mr. Ulrich regards the Ste. Genevieve as the base of the Chester group. Mr. Keyes[a] considered it to belong to the St. Louis, to which it is much more closely related lithologically than to the overlying Cypress sandstone.

CYPRESS SANDSTONE.

Character and thickness.—Above the Ste. Genevieve is a massive to heavy-bedded sandstone almost wholly quartzose. So far as has been observed, this formation contains very little shale or argillaceous matter. The lower portion of the sandstone is characteristically heavy bedded, but the upper portion is somewhat thinner bedded to flaggy. Near the middle is frequently a thin bed of chert-bearing limestone carrying a characteristic fauna.

The thickness of the formation in this area may be estimated at 80 to 100 feet.

Distribution and relations.—No attempt has been made in the maps so far prepared to separate the Cypress from the Tribune and Birdsville. It would be possible to do so only on good base maps and with time for detailed studies. The Cypress sandstone is doubtless present at many points in both Hardin and Pope counties, but may easily be confused with certain phases of both the Birdsville and the Mansfield. It may, however, be seen typically developed at both Rosiclare and Shetlerville. At the former locality it caps the Ste. Genevieve limestone in Downeys Bluff, the basal heavy-bedded sandstone being present. At Shetlerville these basal beds are less typically exposed, but the thin limestone member and the overlying flaggy sandstone were recognized by Mr. Ulrich.

Name and correlation.—Cypress sandstone is a name originally proposed by Engelmann[b] for this formation. Equivalent beds have been called Big Clifty sandstone by Mr. Norwood,[c] and Aux Vases by Mr. Keyes.[d] In the early geologic literature of the region most of the exposures of this sandstone were referred to the "Ferruginous sandstone," a term also applied at times to what is here called the Mansfield sandstone.

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[a] Geol. Survey Missouri, vol. 4, 1894, pp. 50, 76.
[b] Trans. St. Louis Acad. Sci., vol. 2, p. 189.
[c] Geol. Survey Kentucky, new ser., vol. 1, p. 369.
[d] Bull. Geol. Soc. America, vol. 3, p. 296.

TRIBUNE LIMESTONE.

Character and relations.—At the Fairview mine the foot wall of the vein at the surface consists of a coarse, crystalline, nonmagnesian limestone, light gray to white in color and containing minor quantities of oolite and of chert. The following fossils were collected from it and recognized by Mr. Ulrich:

Zaphrentis spinulifera.	Zeacrinus manniformis.
Pentremites godonii.	Lyropora rana.
Pentremites pyriformis.	Lyropora subquadrata.
Pentremites tuberculata.	Spirifer increbescens.
Stenopora cervinus.	Spirifer leidyi.

On the basis of these fossils he determined this limestone to be the same as that at Tribune, Ky., representing the middle Chester. It is impossible at Fairview to determine much regarding the relations of the limestone. It is cut off on all sides by faults, and its thickness is somewhat uncertain. The shaft at a depth of 200 feet shows similar limestone on the foot wall. Whether it is indeed the same or represents the Ste. Genevieve can not be positively ascertained, since it is impossible to make a complete examination of the wall rock from the top to the bottom of the shaft. At the first or 30-foot level Eilers mentions calcareous shale, and at the same level disintegrated sandy material may now be observed. This may possibly represent the Cypress sandstone, and, if so, the Tribune would here have a thickness of less than 50 feet. The Tribune limestone has not been definitely recognized at any other point in the two counties, though there are at a number of points thick limestones which may possibly represent it. At none of them, however, were the fossils found which are considered to be peculiarly characteristic of it.

BIRDSVILLE FORMATION.

Character.—This formation includes sandstones, shales, and limestones. In distinction from the Cypress sandstone below and the Mansfield above, the Birdsville sandstones are particularly thin bedded. They seldom show massive character, and do not, so far as observed, give rise to sharp bluffs and canyons. They frequently grade into shales, becoming less and less sandy until true argillaceous shale is found. The latter is occasionally thin bedded, black, and fissile, and contains thin coal beds. Interbedded with the shale and the sandstone are thin limestone beds. The latter are usually somewhat argillaceous and are chert bearing. They are usually only a few feet thick, though one body having a maximum of 50 feet occurs in the formation.

The general impression of the formation as a whole which one gains from traveling over it is that it is mainly a sandstone. It may

usually be discriminated from the sandstones above and below by the interbedded limestones and calcareous shales, which are easily recognized by the common presence of various species of *Archimedes*.

Thickness.—Not enough detailed observations were made in Illinois to allow an estimate of its thickness to be made. Mr. Ulrich estimates it at 400 to 680 feet, and it can only be said that so far as general impressions go this estimate seems sufficiently conservative.

Distribution.—The Birdsville is the most widespread of the Chester formations in southern Illinois. It outcrops over much of Hardin, Pope, and various counties to the west. On the maps accompanying this report the greater portion of the area assigned to the Birdsville, Tribune, and Cypress formations, which for convenience are mapped together, is really occupied by the Birdsville. Outside of these areas the larger portion of the region shown on the general map (Pl. I) as underlain by the Mississippian has the Birdsville formation at the surface. The particular areas underlain by the earlier formation have already been described.

Since the Tribune limestone is not generally recognized, its absence is presumably due to faulting, by which the Birdsville and Cypress are brought together. Such faults are not easily detected, since rocks of similar lithologic character are brought into juxtaposition. In the Rosiclare area there are probably a number of such faults which are not indicated on the special map (Pl. II). The sandstone in the western part of section 28, for example, is presumably Cypress, since it rests in apparent conformity upon the Ste. Genevieve, and shows a normal erosion edge. In section 30 the sandstone at the surface is interbedded with thin limestones, characteristic of the Birdsville, and yet between the two there is neither any sign of the Tribune limestone nor of a fault such as the stratigraphy calls for. This raises a question as to the integrity of the Tribune formation, a question which can not be settled on the basis of the evidence locally available. The determination must accordingly rest upon Mr. Ulrich's wider studies, and on this basis faulting would have to be inferred as indicated.

Name.—The name Birdsville was given to the formation by Mr. Ulrich from the typical exposures near Birdsville, Ky.

MANSFIELD SANDSTONE.

Character.—The topmost member of the Carboniferous within the district is a massive to thick-bedded sandstone, which is especially characterized by the common presence of small well-rounded pebbles. These are mainly of clear white quartz, but some chert is also present. In the absence of the pebbles it is difficult to distinguish the Mansfield from the Cypress and certain beds in the Birdsville.

It is quite possible that outliers of it have been overlooked. It very commonly carries small flakes of mica, and these are rare, at least in the other sandstones. This fact is of material assistance in recognizing it. The formation seems to rest unconformably on the Birdsville.

Distribution.—The Mansfield sandstone outcrops around the northern and eastern sides of the district, and its edge practically marks the limit of the productive territory. It rises in sharp bluffs, forming Karbers Ridge, as already discussed. South of this escarpment there are a number of outliers formed of fault blocks let down into the older formations. A few of them are indicated on the general map. No attempt has been made to map all of them, and the Mansfield has not been especially studied in the course of this work, and no estimate of its thickness was made.

Name and correlation.—The name used here for these beds is that adopted by the Indiana geological survey. Formerly the beds were commonly referred to as the Conglomerate measures or the Millstone grit. The Mansfield forms the base of the Pennsylvanian series of coal measures and is regarded as of late Pottsville age.

TERTIARY DEPOSITS.

In the southern part of Pope County, including the highland south of Bay Bottoms, scattered pebbles and thin beds of gravel make their appearance on top of the Carboniferous formations. The pebbles are well rounded and seemingly waterworn. They vary in size from a half inch to two inches in diameter and exhibit considerable heterogeneity as to both composition and material. Pieces of quartz, quartzite, sandstone, and chert are common. The chert frequently contains fragments of fossils, so far as observed, of common Carboniferous species. The pebbles were not observed elsewhere in the district, but near the old shaft immediately east of the main working shaft of the Rosiclare mine there are numerous similar pebbles scattered over the surface. Among them was one rounded and apparently waterworn pebble of galena showing quartz crystals in a small druse. It is possible that these represent remnants of a former extension of the formation. In general all the pebbles observed are such as might have been derived from the destruction of local formations.

No special study of these gravels was made, nor were the green sands, said by Worthen to accompany them in Pulaski County,[a] examined. Worthen determined these beds to be of Tertiary age. Mr. McGee[b] has referred them more specifically to the Lafayette formation.

[a] Geol. Survey Illinois, vol. 1, 1866, pp. 44–47.
[b] Twelfth Ann. Rept. U. S. Geol. Survey, pt. 1, 1891, p. 469.

QUATERNARY DEPOSITS.

LOESS LOAM.

Throughout the two counties there is commonly a surface material of light-buff, pebbleless clay or loam. This is spread as a thin mantle over the underlying rocks, and over the flat uplands, in particular, is widespread. On the slopes it is cut away or so mixed with residual material as to be indistinguishable. In places the sand contributed to it by the decomposition of the local rocks is very abundant. In other places, however, it exhibits all the characteristics of upland loess of the glaciated area farther north, and it is doubtless a phase of one of the older loess sheets which have been there discriminated.

ALLUVIUM.

Along the Ohio and many of its tributaries are numerous broad, flat bottom lands underlain by alluvium. No attempt has been made to discriminate them on the accompanying maps, nor has any study been made of the interesting and complex river history which they in part record.

DESCRIPTION OF IGNEOUS ROCKS.

GENERAL STATEMENT.

The discovery of intrusive igneous rocks in Illinois was very recent. In 1889 Mr. Ulrich, while working for the Kentucky Geological Survey, discovered the Flannery dike in Crittenden County, Ky., and in 1892 Mr. J. S. Diller described the rock. From time to time other dikes were found in that State, until now a considerable number are known. In 1902 Mr. W. S. Tangier Smith located the Mix dike above Golconda, that being the first found in Illinois. In the course of the work in 1903 a number of additional dikes were found, and there are doubtless others which as yet remain undiscovered. Near Hicks Mr. Crider found considerable mica in one of the streams, and Mr. F. Julius Fohs has furnished a specimen of a mica-bearing rock picked up nearby. So far, however, it has proved impossible to find material in place.

The dikes so far found are indicated on the accompanying maps. In no case has a dike been traced any considerable distance, and with two exceptions they are found only in the bluffs of the Ohio and for a short distance inland. The dike in Downey's bluff at Rosiclare sends off a thin sheet which is intruded into beds of the Ohara member of the Ste. Genevieve. The dike at Orr's landing has a thin stringer running off into the St. Louis limestone. With these exceptions the igneous rock so far as known occurs only in normal, vertical dikes.

The individual occurrences are described below, grouped by localities, the petrographic notes being by Mr. Albert Johannsen, of the United States Geological Survey. He makes the following general observations on the rocks, based on an examination of material from both the Kentucky and Illinois occurrences:

So far as they can be determined from the altered state of most of the rocks, they fall into two groups, mica-peridotites and lamprophyres, the majority of the specimens belonging to the latter. In all the specimens (of the lamprophyre) the original minerals are so much altered to calcite that subdivision is impossible, for in no case is there any of the feldspar remaining. It is possible that there was originally no feldspar, although the disposition of the particles and replacement products seems to point in some of the thin sections to a groundmass originally in lath-shaped crystals.

There is a sharp distinction between the mica-peridotites and the lamprophyres, however, in that in the former, olivine, either partially or entirely serpentinized, is clearly shown, while in the latter there is no indication of its ever having occurred; again, in the latter there is a remarkable and unusual occurrence of apatite. This occurs in nearly all of the lamprophyre slides in large, perfectly fresh, short, thick prisms, their unchanged condition making a striking contrast with the state of alteration of the remainder of the sections. The presence of phlogopite in both groups, rather than a more usual variety of mica, connects them in a manner.

Orr's landing.—About a quarter of a mile below Orr's landing (SW. ¼ NE. ¼ sec. 33, T. 12 S., R. 8 E.) the St. Louis limestone is cut near the water's edge by a vertical dike about 10 inches thick. This shows, on superficial examination, very little igneous material. The bulk of the dike is made up of clastic material, consisting of rounded pebbles of limestone and quartzite. These attain a maximum diameter of 6 inches, and, while the country rock is St. Louis limestone, they include lithologic types not found in that formation. The pebbles are in a matrix of dark calcareous material, in which, on examination, Mr. Johannsen found much pyrite, some magnetite, quartz, and large apatites. He regards it as a lamprophyre now nearly entirely altered to calcite. There are 3 to 4 inches of calcite parallel to the dike material and separating it from the wall, and in small seams intersecting the whole calcite and fluorite are developed together. On the east side of the dike a narrow irregular crack leads off through the limestone for a number of feet. Along either side of this crack the limestone is altered and darkened for about 2 inches.

This somewhat peculiar dike seems to represent the intrusion of liquid and not entirely dry magma into an open crevice partially choked by gravel and waterworn material washed in from above. There has been apparently some slight alteration of the limestone, though the nature of this alteration has not been studied, and whether the introduction of the fluorine was incident to it is wholly unknown.

Rosiclare quarry.—In the quarries in the Ste. Genevieve limestone

mmediately above Rosiclare landing there are two dikes which Mr. ohannsen describes as follows:

Megascopically the rock is much altered, and at first sight it appears to be a nglomerate with included fragments of shale. These shaly particles are, however, an alteration product of mica, as is shown by thin sections under the icroscope. Microscopical examination shows the rock to be almost entirely tered to calcite. Large apatites, iron oxide, chlorite, and serpentine occur.

The two dikes are about 10 feet apart, and are each about 10 inches ick. They are vertical and apparently do not mark faulting planes. he limestone in contact with them shows no apparent alteration, but arallel with them and disposed on either side are a number of promient veins of calcite carrying smaller amounts of fluorite. The whole ystem of veins and dikes has a course about N. 45° W.

A single specimen of ordinary diabase was obtained from near here i the town of Rosiclare. It was found in digging a well, but as the lations are not known it possibly represents material brought down ie river during Glacial times, and until further data are available it in hardly be considered as representing another dike.

Downey's bluff.—In the high bluff between Rosiclare and Fairview ndings is one of the most interesting of the occurrences. The rock found here both in a well-defined dike, cutting the point of the hill ith a course N. 31° 30′ W., and in a thin sheet intruded between eds of the limestone lying above the Rosiclare sandstone member. he dike itself is 4 to 5 feet wide. The main sheet running off from is 6 inches thick, and about 3 inches above this is a second sheet arely 1 inch thick. The two are connected by very thin stringers f igneous material, indicating apparently a condition of high fluidy. The dike does not mark a faulting plane, though on the northest side of the hill the sheet is cut off by an east-west fault of 70 et, with downthrow to the north. The dike has been traced to ie north about 1,000 feet to a spring, beyond which it is either it off by the fault or fails to outcrop because of the presence of lluvium.

Despite the penetration of the rock into the thinnest crevices of ie limestone, there is no macroscopic evidence of the alteration of ie latter by contact metamorphism. Mr. Johannsen examined a umber of specimens of the contact rocks, and notes that "there is othing to indicate a change caused by the intrusion." His petroraphic description of the rock, which he determines as a lamprohyre, is as follows:

Megascopically this is a very dark porphyritic rock, consisting of a fine-ained groundmass full of phenocrysts of dark mica and pyroxene. The mica enerally occurs in basal sections of about 1 mm., though occasionally crystals over a centimeter occur. The crystals of pyroxene are of small dimensions,

Under the microscope the structure is holocrystalline porphyritic, the groundmass being much less in amount than the phenocrysts. The phenocrysts are irregular in outline and of varying sizes, and are, in the order of their importance, mica, pyroxene, apatite, iron oxide, and, possibly, perofskite. The mica occurs in large crystals and is chiefly phlogopite, with biotite in lesser amount. The iron mineral is titanite and, possibly, considerable titaniferous magnetite. Pyrite occurs in several of the slides. The pyroxene is usually much altered, but in section No. 4 there are remnants of a pleochroic augite. The groundmass is largely altered to calcite. The secondary products are calcite, serpentine (from pyroxene), leucoxene, and quartz.

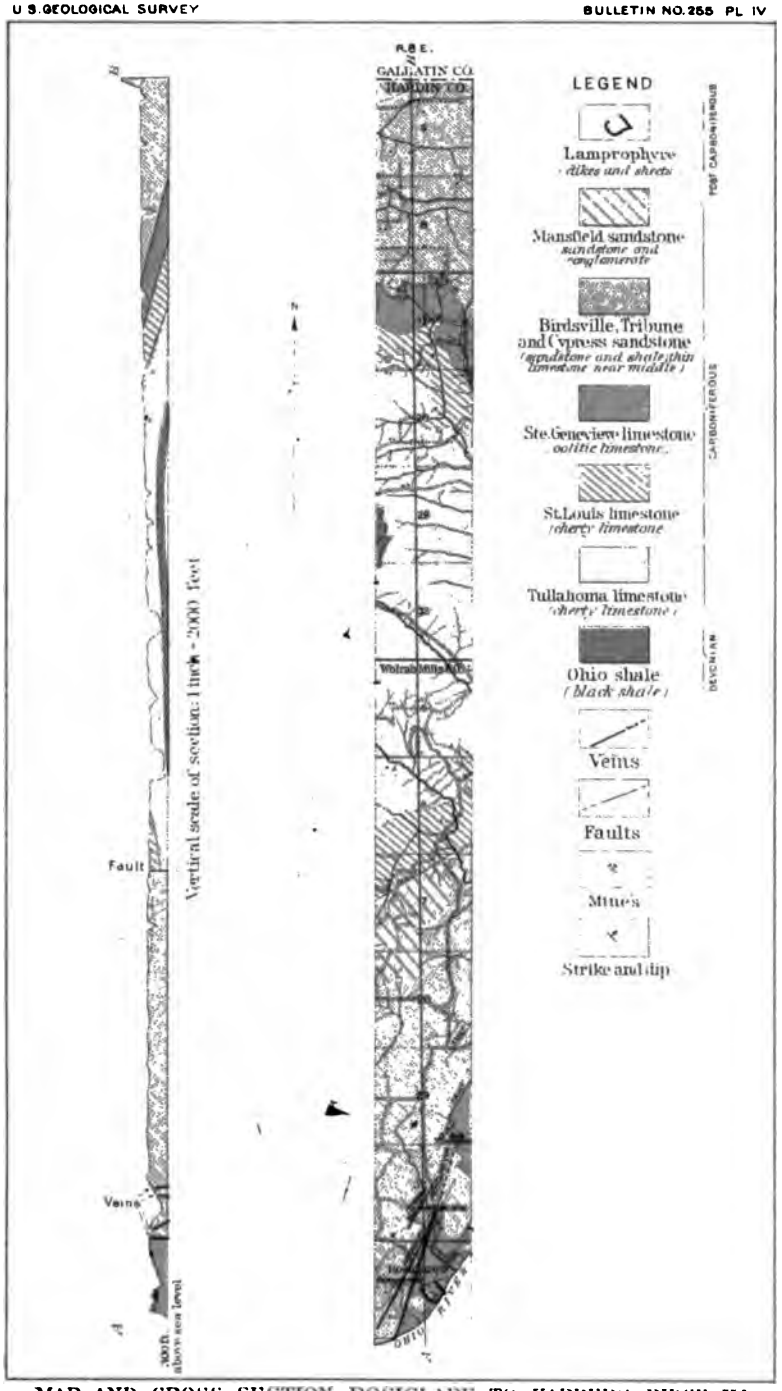
Soward farm.—Northwest of Rosiclare (W. ½ sec. 31) is an interesting occurrence of dike form which possibly indicates the presence of igneous rock a little below the surface. The rock itself is clastic, and shows both angular and rounded fragments of limestone, with flakes and bits of black shale cemented by a limestone matrix. Some very altered ferruginous material may represent igneous rock, but this is uncertain. From the mode of occurrence it is possible that this represents a fissure filling, largely of material brought up from below by the intrusion underneath. It is mentioned merely as a place at which it is thought igneous rock may yet be found in situ.

Mix farm.—There are two dikes known in Pope County. One of them is that discovered in 1902 on the Charles Mix farm, a few miles above Golconda (sec. 8, T. 13 S., R. 7 E.). It cuts Chester sandstone, presumably of Birdsville age, and has a course about N. 40° W. It shows only in the river bluff, and apparently the intruded rock has not been in any way altered. Mr. Johannsen determines the rock to be a mica-peridotite, somewhat similar to that described by Diller, and describes it as follows:

The hand specimen consists of a dark, granular, mottled black and white groundmass, with phenocrysts of mica and pyroxene. Under the microscope they very closely resemble the sections of the Flannery dike. They consist chiefly of phlogopite, serpentine, ilmenite, leucoxene, perofskite, magnetite, and a little pyroxene and olivine. The olivine is only partially altered to serpentine.

Golconda.—The second occurrence of dike material noted in Pope County is that found a short distance west of Golconda, at the Gilbert prospect. This dike is 4 to 5 feet thick, vertical, and cuts Chester—presumably Birdsville—sandstone and shale without faulting them. Mr. Johannsen describes the rock as follows:

A pyroxene-lamprophyre, consisting of much calcite, chlorite, iron oxide, some phlogopite, leucoxene, and some serpentine after pyroxene and, doubtfully, after olivine. The iron oxide is ilmenite, and probably some titaniferous magnetite occurring in cubical crystals. A little hematite occurs.



MAP AND CROSS SECTION ROSICLARE TO KARBERS RIDGE, ILL.

BY

H.FOSTER BAIN, ASSISTED BY A F CRIDER AND E.O ULRICH

Scale

0 ½ 1 2 3 miles

1904

JULIUS BIEN & CO. N.Y.

GEOLOGIC STRUCTURE.

GENERAL RELATIONS.

The structure of this district stands in marked contrast with that of the remaining portion of Illinois. The widespread presence of extensive faulting and the intrusion of igneous rocks set it off sharply from the general surrounding region. If the Kentucky-Illinois district be considered as a whole, it seems to represent a portion of an extensive northwest-southeast monocline or, possibly, the northeast half of a dome whose remaining portion has disappeared beneath the Tertiary deposits of the Mississippi embayment. To the north and east the Mansfield sandstone dips sharply away and becomes deeply buried beneath the Coal Measures strata. To the south and west the beds pass, with little dip and no uniformity, beneath the later sediments. Loughridge gives data suggestive of faulting along the contact,[a] and it may be that beneath the Cenozoic beds of that region there is deeply buried a structural remnant corresponding to that remaining on the other side of the district. Be that as it may, there are within the district many evidences of local disturbance. These include a sharply defined little dome near Hicks, in Hardin County, and numerous faults throughout the territory. (Pl. IV.)

HICKS DOME.

This is a nearly complete uplift about 7 miles in diameter. Since the black shale of the Devonian is brought up to the topographic level of the upper Birdsville within 3 miles, a vertical uplift of at least 1,000 to 1,500 feet has taken place. To the southeast the dome is cut off by a normal fault of 1,000 feet or more, by which Mansfield sandstone is brought into contact with St. Louis limestone. Around the edges of the dome, as in the vicinity of the Empire mines, there are numerous normal faults, though none of them, so far as has been determined, have much throw. Their presence none the less renders it improbable that the dome was raised by ordinary lateral thrust and indicates rather vertically acting forces. This conclusion is reenforced by the fact that normal faulting, almost exclusively, occurs in the district as a whole.

Around the edge of the dome the rocks have quaquaversal dips of high angle. Along Hicks Branch, in sec. 26, T. 11 S., R. 8 E., the dips are 10° to 20° to the south and west. On the northeast the dip in section 17 is 5°. On the southeast, in section 31, it is 11°, and on the southwest, in section 35, the dip is 8°. The dip decreases from the center outward. The occurrence of the St. Louis along Hicks

[a] Geol. Survey Kentucky, Jackson Purchase Region, 1888, p. 267.

Branch, and along a branch of Big Creek in section 20 (Pl. III), indicates a local irregularity in the dome.

There are no known occurrences of igneous rock connected with the Hicks dome, but the presence of unusual quantities of mica in the streams at one or two points lends color to the suspicion of their presence.

FAULTS.

Normal faults are found throughout the two counties. A number of these are represented upon the accompanying maps, and their particular relation to the ore deposits will be discussed later. The throw varies from an imperceptible amount to 1,000 feet or more. All the Carboniferous formations are affected. East of Cave in Rock the Mansfield sandstone and the Ste. Genevieve limestone are brought together. On Hog Thief Branch (sec. 30, T. 11 S., R. 9 E.) the St. Louis limestone is brought into contact with the Mansfield and with either Cypress or Birdsville sandstone. In the region beween Elizabethtown and Karbers Ridge there are many faults, and rapid changes in strata may be noted in traversing any of the roads. In Pope County, from the Ohio and the Bay Bottoms to the encircling escarpment of Mansfield sandstone, faulting is a common phenomenon, and in Gallatin County (sec. 21, T. 12 S., R. 7 E.) the Mansfield itself is cut by faults in numerous directions.

There is no regularity as to the trend of the fault planes, though a majority of those so far studied have a general course north of east. The individual fault planes are rarely traceable more than 1 or 2 miles, but along the same general course faulting occurs for 12 to 15 miles. For example, from the Empire mine (sec. 34, T. 11 S., R. 7 E.) to the Wright prospect (sec. 3, T. 13 S., R. 5 E.) there is a succession of prospects and evidence of disturbance of the beds, though there is small probability of a continuous fault. From the Rosiclare and Fairview mines the general course of the faulting may be projected southwest to Bay City, and along the line frequent evidence of disturbances will be found, while at Bay City there is also mineralization.

On the other hand, there is usually clear evidence that the individual faults are of limited length. They occupy en échelon positions and are by no means exactly parallel. This is illustrated on the special map of the Rosiclare district, where the various fault planes are offset as indicated, and vary in direction nearly 30°. This tendency of fault planes to take a course at a slight angle with what appears to mark the line of major stress is believed to be the expression of a general law. The reason is not well understood, but seems to lie in the character of the rocks and the direction of the

stress. It is perhaps due to the presence of a slight horizontal element in the latter.

The fault planes are usually vertical. The Rosiclare vein, occurring along such a plane, has been mined to a depth of 300 feet, and in that depth is so nearly vertical that the shaft is still within the vein. The Fairview vein has an average dip to the west of 79° 30′. The Hamp vein dips S. 68°. The Empire vein dips E. 73°. Even these departures from the vertical seem, on the whole, to be exceptional, and the total effect of the faulting has been to divide the nearly horizontal rocks into a series of polygonal blocks, which have been raised or lowered with reference to one another, but with very little horizontal displacement. This type of structure, while perhaps common, has been but little discussed. Mr. G. K. Gilbert some years ago pictured [a] it, and Powell gave it the name "diverse displacement." It is, as he remarks, the Kaibab structure on a small scale. Recently Prof. W. H. Hobbs has called attention [b] to faulting somewhat similar in character; and in the Globe district of Arizona Mr. F. L. Ransome has described an intricate system of small normal faults, apparently very much like these.[c] In the Columbia folio,[d] Hayes and Ulrich have mapped one block of strata, evidently bounded by similar fault planes, but with this exception the structure has not been described from the Mississippi Valley. Its occurrence here is quite in keeping with the general peculiarities of the district, which set it off from the remaining portion of the geologic province within which it occurs.

QUARTZITE REEFS.

The fault planes are commonly marked by the development parallel with them of closely spaced fractures. Where these affect sandstones and the latter have been changed to quartzite by the addition of silica, reefs or ridges of quartzite, not unlike dikes in topographic expression, are formed. These afford the most obvious means of recognizing fault planes. The juxtaposition of rocks of diverse lithologic character, such as sandstone and limestone, is also indicative of faulting, though occasionally the outcropping edge of a limestone interbedded with sandstone and shale becomes deceptive.

DIP.

Near fault planes the rocks often dip at a high angle, and this seems to be especially true in the western part of the district, where

[a] Powell, Geology of the Uinta Mountains, 1876, figs. 4 and 5, pp. 16–17.
[b] Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 3, pp. 19–162.
[c] Geology of the Globe copper district: Prof. Paper U. S. Geol. Survey No. 12, 1903, pp. 97–106.
[d] Geologic Atlas U. S., folio 95, U. S. Geol. Survey.

deformation apparently has been accomplished in part through monoclinal folding rather than fracturing. At the Wright prospect, near Rock, the sandstone and shale in the creek strike N. 60° E. and dip 42° NW. About 500 feet farther west the strike is N. 45° E. and the dip 40° SE. About a mile and a half east of Resort (sec. 9, T. 13 S., R. 5 E.) there is a considerable belt of limestone striking N. 35° E. and dipping sharply to the southeast. Near the Luella mines (sec. 10, T. 12 S., R. 6 E.) dips as high as 50° were observed, and in a belt approximately parallel to the fault plane sandstone, shale, and limestone pass successively beneath the surface. Near Packers Gap (NE. ¼ sec. 16, T. 11 S., R. 7 E.) heavy beds of sandstone striking N. 80° W. have a dip SW. 49° and show evidence of some displacement between the beds. North of Elizabethtown on the Patton land (sec. 21, T. 11 S., R. 9 E.) there is a belt of rocks 1,200 feet across, dipping 10° SE. and striking N. 30° E. The rocks include sandstone, shale, and thin limestones, such as characterize the Birdsville formation. There are minor faults and local evidences of thrust.

These varying dips are notably irregular, and in no case studied did they indicate a regular system of folds. Occasionally, in connection with the displacement, comprehensive stresses have been generated, but these seem to have been entirely local in their effect and incident to the general deformation by diverse displacement.

GEOLOGIC HISTORY.

PERIODS OF SEDIMENTATION.

Of the pre-Devonian history of this area nothing is definitely known. There are no exposures of earlier rocks in the district and there are no drill records reaching below the black shale. In the adjacent Ozark region, resting on pre-Cambrian granites and porphyries, are Cambrian, Ordovician, and Silurian rocks, consisting largely of magnesian limestones, dolomites, and sandstones. The contemporaneous rocks in the region south and east are largely nonmagnesian limestones and shales. In the absence of data it is uncertain what kind of rocks were deposited here, and it can only be inferred that in pre-Devonian time the area was one of sedimentation, interrupted at intervals by periods of erosion. From Devonian until late in the Carboniferous at least, similar conditions prevailed. At times the area was covered by the sea and at times it formed part of the land. The details of this history have not been made out, and, so far as known, are not significant from the present point of view.

DEFORMATION AND INTRUSION OF IGNEOUS ROCKS.

At some time after the deposition of the Mansfield sandstone, and presumably after the deposition of a considerable thickness of coal measures, the region was uplifted and exposed to erosion. This may well have been merely a recurrence of uplift along a line marked out by previous deformation, since in the total unlikeness of the pre-St. Louis Carboniferous beds of this district to those along the Mississippi to the northwest there is evidence of an old barrier between the two provinces. However that may be, the particular uplift mentioned was either in the Carboniferous or later. It was accompanied or succeeded by fracturing and diverse displacement, and since this form of deformation probably occurs only when the beds are lightly loaded it took place either before any great thickness of coal-measure shales was deposited over the region or after they were eroded. If account be taken of the large amount of erosion which the Mississippi Valley has undergone in Mesozoic and Cenozoic time, it seems probable that this uplift occurred after a considerable thickness of rocks—later than any now known in the area—was deposited. In central and southern Illinois there are 1,000 feet or more of coal measures which are unrepresented in Pope and Hardin counties. As these beds are nowhere preserved in the fault blocks of the latter area, there would seem to have been first an uplift of the district as a whole, followed by erosion, and this in turn by fracturing and displacement of the individual blocks of strata.

While the hypothesis is not perhaps susceptible of absolute demonstration, the intrusion of the igneous material seems to have accompanied the fracturing and displacement. The relations of the dikes to the faults are not clear. In general the dikes seem to occupy fractures along which there is practically no faulting, and the deep fault planes are not occupied by igneous material, though they are frequently the locus of veins. The occurrence in the north flank of Downey's bluff of a fault cutting the small sheet of peridotite of course merely proves that some faults are later than some intrusions.

No attempt to fix more definitely the age of the dikes and deformation will be made, as any suggestion would rest wholly on analogy with neighboring regions showing similar phenomena, and there are none sufficiently close to give much weight to such suggestions.

PERIOD OF EROSION.

Since the deformation, the faulting, and the intrusion of the dike material there has been prolonged erosion of the area. It is extremely probable that this erosion has occurred in two or more cycles, but of the earlier ones there is now no demonstrable evidence.

The upland plain previously discussed marks the last of the important cycles of erosion, and its age has already been suggested to be Lafayette or late Tertiary. At the completion of this cycle Karbers Ridge, the Shetlerville Hills, and certain areas in Kentucky remained as monadnocks rising above the plain. Since its completion the country has been elevated as a whole 200 feet or more, and the streams have cut their present channels. This elevation seems not to have been continuous, since there are traces of incomplete peneplains below the main one and above the bottoms of the rivers.

THE ORE DEPOSITS.

GENERAL CHARACTER.

The ore deposits of Pope and Hardin counties are vein deposits occurring along faulting fissures. The vein material consists essentially of fluorspar and calcite, or "calc spar," as it is locally called. Associated with these minerals are minor amounts of the lead and zinc sulphides, galena and blende. There are also traces of other sulphides, notably those containing copper and antimony. Surface alteration is relatively unimportant, though some carbonate of zinc occurs, and in the adjacent portion of Kentucky one or two bodies of it have been mined. No traces of secondary enrichment have been observed. Within the area are certain bodies of limonite, which were formerly mined, but which are now unimportant. Fluorspar is the only mineral now mined in quantity, and the deposits afford, therefore, an instance of what is ordinarily, and was here originally, merely a gangue mineral, being the one which gives value to the ore.

MINERALS PRESENT.

GANGUE MINERALS.

Fluorite.—This district is characterized by the peculiar and remarkable abundance of the calcium fluoride, CaF_2, corresponding in composition to 51 per cent of calcium and 49 per cent of fluorine (specific gravity, 3.01 to 3.25). This mineral occurs in large bodies of unusual purity, shipments running 98 to 99 per cent being constantly made. Very little running less than 95 per cent finds sale except at reduced price. The mineral is crystallized, and in druses and open spaces well-developed crystals are not uncommon. On these the faces of the cube are best developed, but modifications due to the octahedron may be frequently noted. For the most part the fluorite occurs in great vertical sheets or veins clearly crystallized, but not showing crystal form. The octahedral cleavage is always well developed, so much so, in fact, that jig concentrates consist largely of imperfect tetrahedra and octahedra. Cleavage forms are easily ob-

tained, and many very perfect ones adorn local cabinets. In the veins a ribbon structure giving the appearance of onyx is occasionally seen. This seems to be dependent upon the distribution of coloring matter. In general the spar is white, but purple, amethyst, green, and golden yellow are also present, in the order of abundance given. The cause of the color was not investigated. Mr. Tangier Smith, from his studies of the Kentucky fluorspar, concluded that the differences in color were determined by the condition of the coloring matter, probably hydrocarbons, present.

The fluorspar is almost universally known by the shortened name of spar, and the clear transparent varieties are known as glass spar. No fluorine minerals other than fluorspar were found in the region, except that in the dike rocks there are unusual quantities of apatite and mica, both of which usually contain fluorite.

Calcite.—The most universal accompaniment of the fluorspar is calcite or calcium carbonate, $CaCO_3$, corresponding to 56 per cent of calcium oxide and 44 per cent of carbon dioxide (specific gravity, 2.71 to 2.72).

This mineral in its impure form constitutes the larger part of the limestones of the region and also occurs in the shales and some of the sandstones. It is the common cementing material where the rocks have been brecciated or fractured, and occurs alone forming important veins, as well as with the fluorite. It is commonly not transparent and rarely occurs showing crystal form, though the usual scalenohedra with rhombohedral terminations occur. The mineral is not itself valuable. It is locally considered an indication of the presence of fluorite and the ore minerals, but occurs so commonly without them that it is of small value in this particular. Calcite is frequently referred to locally as "calc."

Quartz.—In connection with the mineralization of the veins, large quantities of silica, SiO_2, have been added to that already present in the sandstones and other rocks. This silica has been deposited especially between the grains of sand of the original sandstones along the veins, firmly cementing the rock and giving rise to the quartzite reefs already mentioned. In druses in the vein and elsewhere the silica has also crystallized, forming small pyramidal crystals, some transparent and others jet black.

Barite.—Somewhat widely distributed but in relatively smaller quantity than the minerals enumerated above is barite, the barium sulphate, $BaSO_4$ (specific gravity, 4.3 to 4.6). This occurs as a massive, white, crystalline substance intimately intergrown with the other minerals. Occasionally on the free surfaces of druses it shows crystal form, small tabular crystals clustered so as to form mammillary aggregations being characteristic. In this it resembles the barite occurring in southeastern Missouri. The larger clear crystals, such as

occur in southwestern Missouri, were not noted, though possibly present. The mineral is locally known by the common name, heavy spar.

Dolomite.—The double carbonate of magnesium and calcium, while possibly present in occasional small quantities, was nowhere noted, though Mr. Fohs has shown the writer the iron-manganese-magnesium-calcium carbonate, ankerite, from one of the Kentucky mines. Dolomite is probably present, but only in very small quantity, a fact of some possible significance as related to the genesis of the ores.

Kaolin.—The hydrous silicate of alumina ($2H_2O,Al_2O_3,2SiO_2$) occurs near the Pittsburg mine in considerable quantity. It does not seem to be directly related to the ores, and its origin is in doubt.

ORIGINAL METALLIC MINERALS.

Galena.—The sulphide of lead, PbS, containing 13.4 per cent of sulphur and 86.6 per cent of lead (specific gravity, 7.6), is probably the most abundant and widespread of the original metallic minerals. It occurs in the usual cubical crystals, occasionally showing the faces of both cube and octahedron. It is intimately associated with other sulphides and with gangue minerals. The galena of this district is argentiferous, at least to a degree notably beyond that of other deposits in the Mississippi Valley. Whitney[a] gives an assay showing the presence of 9½ ounces of silver to the ton in galena from Rosiclare, and Eilers quotes the statement of the owners of the old Mineral City property to the effect that 8 to 14 ounces were commonly found in the ore yielding 12 to 20 ounces in the pig. Whether this amount is constant or not is uncertain, and no attempt has been made, so far as is known, to save the silver, nor does its presence affect the price of the lead.

The lead ore now obtained comes mainly from the jigs employed to clean the fluorite, and its production is incidental to the preparation of the latter for the market. Large bodies of galena corresponding to those formerly mined do not seem to be anywhere in sight at present.

Blende.—The zinc sulphide, ZnS (sulphur, 33 per cent; zinc, 67 per cent; specific gravity, 3.9 to 4.1), locally known as "jack," is, next to galena, the most abundant of the sulphides. It occurs crystallized but rarely with crystal form. The blende present is usually quite pure, being a brown "rosin jack," and apparently rather free from any admixture of pyrite. While many hand specimens and even small quantities of ore can be found running high in blende, no considerable bodies rich enough to warrant independent mining were exposed when the area was visited. At the Rosiclare mill middlings containing zinc are being accumulated with a view to possible future sale.

[a] Whitney, J. D., Geol. Survey Illinois, vol. 1, 1866, p. 189.

Pyrite.—The iron sulphide, probably in the main pyrite, FeS_2, is as usual widely disseminated. It is, however, distinctly subordinate in quantity, and in this particular the district is in contrast with many of the mining districts of the West.

Chalcopyrite.—The copper-iron sulphide, $CuFeS_2$ (sulphur, 35 per cent; copper, 34.5 per cent; iron, 30.5 per cent; specific gravity, 4.1 to 4.3), occurs in minute quantities, and small crystals may frequently be observed by carefully examining the ores. It is not of any economic importance here.

Stibnite.—The antimony sulphide, Sb_2S_3 (sulphur, 28.6 per cent; antimony, 71.4 per cent; specific gravity, 4.52 to 4.62), has been reported by Mr. Bisland, of the Fairview mine, and Eilers mentions its presence and also that of a mineral taken to be jamesonite. He speaks of these as being in such small quantity as to interpose no difficulties in smelting and to be of no value.

SECONDARY MINERALS.

Cerussite.—The lead carbonate is reported to have been found in small quantities in the early days of the mining industry. It has long since disappeared and probably never was abundant.

Smithsonite.—Zinc carbonate, $ZnCO_3$ (carbon dioxide, 35.2 per cent; zinc oxide, 64.8 per cent; specific gravity, 4.30 to 4.45), occurs frequently in connection with the alteration of the blende. It is a rusty-looking material, not unlike some of the weathered chert in appearance, but readily distinguished by its weight. The only body of any size noted in the course of the survey was at the Empire mine, and the quantity present here, while undetermined, was not impressive.

Limonite.—The hydrous oxide of iron occurs in the region in considerable abundance, and formerly there were two furnaces—the Martha and the Illinois—making iron from it. The ores are low grade, as judged by present standards, and, as they bear no obvious relationship to the minerals under investigation, were not especially studied. Small bodies of impure iron oxide or ocher are here, as usual, widespread.

Malachite.—The copper carbonate, $2CuCO_3,Cu(OH)_2$, occurs as a greenish stain at a number of points, particularly at the so-called "copper vein" near Elizabethtown. The quantities observed were everywhere inconsiderable.

Copper.—Small flakes of native copper may be occasionally observed in the Rosiclare ores. They seem to be due to local reduction of the minute quantities of chalcopyrite.

PARAGENESIS AND ASSOCIATION.

No definite order of deposition of the original minerals can be made out. The various metallic sulphides and gangue minerals seem to have crystallized at the same time, and beyond the general fact of the replacement of calcite by fluorite there seems to be no system in their deposition. All of the sulphides occur completely surrounded by the fluorite. There are none of the common evidences of secondary enrichment, and in the veins the oxidation incident to the long period of erosion subsequent to the formation of the ore bodies has left few traces. Apparently the sulphides, being practically sealed up in fluorite, are, so long as they remain in the vein, almost entirely unaffected by surface waters. Minor exceptions are noted in the descriptions of the individual mines. In general the ore bodies are believed to be practically unmodified ores of primary deposition, or of first concentration, as Professor Van Hise defines the term.[a]

MODE OF OCCURRENCE.

Form and character of the ore bodies.—The deposits of this district form typical fissure veins. The ore bodies are tabular; they occur along planes that mark extensive faulting and that cut across the strike and dip of the strata. Ore and gangue minerals in considerable variety are present, and both fissure filling and metasomatic processes have operated in their formation. The ore bodies are unusual in respect to thickness—frequently 10 to 12 feet, and occasionally 25 feet or more—and in the great purity and abundance of the fluorite.

The development work at Rosiclare gives some idea of the size of at least one of the ore bodies. Mining has been carried on for practically the whole distance of three-fourths of a mile along the vein. For the greater portion of this length the stopes have been 10 to 20 feet wide in very clean ore. In the Fairview shaft, at one end, levels at a depth of 200 feet show the presence of a vein of undiminished strength and an ore body of the full normal thickness. At the other end the Rosiclare shaft shows the same thing to a depth of 300 feet. Beyond these shafts very little work has been done, but even if the vein or ore shoot—the two terms here seem almost synonymous—goes no farther laterally, a very large body of spar is shown.

This is the largest body of fluorspar yet developed in the two counties, but it is also the only place at which any considerable sinking and drifting have been done. As the mine descriptions show, there are a number of other points at which present indications point to large ore bodies.

[a] Van Hise, C. R., Some principles controlling the disposition of ores: Trans. Am. Inst. Min. Eng., vol. 30, 1901, p. 173.

In general the great width of the vein is probably due to the facility with which the less soluble calcium fluorite is formed in the place of calcium carbonate whenever fluorine is available. This has resulted in extensive replacement of the limestone wall through metasomatic processes, as was long since pointed out by Emmons.[a] The detailed microscopic evidence of this is given in connection with the description of the Lead Hill mine. This process is not believed, however, to have operated to the exclusion of normal vein filling in open cavities, since, for example, in the McClellan mine, later described, there is a considerable body of clear fluorspar where both walls are sandstone and where, accordingly, there is little opportunity for simple replacement. The occasional banding of the ore, while not conclusive evidence, and often, indeed, the reverse, points, nevertheless, to the same conclusion. The cooperation of the two processes of open fissure filling and metasomatism is, as Mr. Lindgren has shown,[b] normal and quite in accord with what should be expected.

In connection with the veins, the wall rock, where composed of sandstone, is commonly converted to a quartzite. As this is a local phenomenon, the quartzite occurring only along the veins, it points apparently to the introduction of considerable amounts of silica at the time the ore bodies were found—a conclusion apparently confirmed by the presence of crystals of quartz intimately intergrown with the ore minerals.

Ore shoots.—So far as is known, the ore does not occur in regular ore shoots. In view, however, of the small amount of development work and the smaller amount of mining so far done, this appearance may be deceptive. The Fairview-Rosiclare ore body, if it be regarded as a single ore shoot, is certainly one of unusual size.

Structural relations.—The veins are developed, as already indicated, along fault planes, but these are neither necessarily nor frequently planes of major faulting. The Hamp mine, which shows an excellent body of ore, is in a vein where there has been very little faulting. At the Empire mine, while there has been considerable faulting in the vicinity, the ore body is found along a plane which seemingly marks very little displacement. This is, however, a common phenomenon. For some reason not well understood, the large faults do not form the locus of ore bodies any more commonly than smaller faults in their vicinity.

The ore bodies so far developed are usually found where one wall is a sandstone and the other a limestone, generally the Ste. Genevieve. The Fairview and Rosiclare may be cited as examples. They also occur where both walls are limestones, as at the Hamp and Empire,

[a] Loc. cit., p. 51.

[b] Lindgren, Waldemar, Metasomatic processes in fissure veins: Trans. Am. Inst. Min. Eng., vol. 30, 1901, pp. 578–692.

and where both are sandstones, as at the McClellan and probably the Daisy. Since the faulting is deep enough to cut a considerable succession of sandstones and limestones, it is obvious that if the ores continue to any depth the relations at the surface may change, even to the point of reversal. In such a region as this it is also true that the fault planes which bring limestone into contact with sandstone are most easily recognized, and hence are the ones first prospected. Under the circumstances the seeming close relation of the ores with the Ste. Genevieve limestone may be deceptive, though in the absence of deep mining judgment on the point must be suspended.

Relations to topography and underground water level.—The ore bodies do not seem to bear any close relation to topography. They are found on the upland, as at the Empire; in hillsides, as at the Lead Hill mine, and under bottom land, as at the Rosiclare. In general they are on the slope, since there is very little level ground in the district. There is not, however, that close relation to topography which, for example, is characteristic of the ore bodies of the Lake Superior iron ranges.[a]

The relations to underground water level appear to be equally fortuitous. In general, the mines are relatively dry and the small amount of water handled seems to be entirely of local origin. At the Rosiclare mine it is clearly oxidizing and varies with local rainfall. As this is the deepest mine, it would presumably have tapped any deep waters which might occur in the veins, and yet the total amount of water pumped under ordinary conditions is very small, being estimated at 75 gallons per minute. In general, the mines, where of any depth at all, are below the local level of underground water.

Alteration of ores.—The ores are very little altered. Beyond the occasional occurrence of small bodies of zinc carbonate near the surface, there are none of the usual signs of decay and alteration common to sulphide ores. Even where oxidation has been carried to some depth, as at the Hubbard and Cook mines, it has not much affected the vein matter, but has proceeded rather along cross fractures or through the country rock. In the long period of erosion in which the upper portion of these veins was cut off, very little material was carried down into the vein. That which was eroded seems to have been mechanically broken off or to have been dissolved and carried away without local reconcentration. In the presence of the more easily soluble limestone, surface waters do not attack with any vigor the fluorite or the minerals confined within it, and so the vein material as now exposed is practically unaltered. The bodies of zinc carbonate occasionally found mark local and exceptional reconcentrations.

[a] Van Hise, C. R., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 3, 1901, pp. 329–330.

Age.—The ores were formed after the period of deformation, which, as has already been shown, was late in the Carboniferous or after the close of that period. They originated before the Lafayette peneplain was cut, and they do not seem to be forming now. They may be as old as the Permian or as young as middle Tertiary, but it is impossible to fix their age more definitely on the basis of local evidence.

Genesis and value.—These topics will be discussed in detail after the description of the individual mines.

DESCRIPTION OF MINES AND PROSPECTS.

ROSICLARE AREA.

Résumé of geology.—The formations exposed near Rosiclare have already been discussed, but a brief résumé with certain additional details will help in understanding the mine descriptions.

The southeastern portion of the area (Pl. II), extending from Elizabethtown to Orr's landing and back to the crossing of Big Creek by the Golconda road, is underlain by the St. Louis limestone. This formation is brought into faulting contact with the Chester formations, though probably in part at least the boundary between it and the Ste. Genevieve is a normal erosion boundary. So far as known no ore bodies have been found in the St. Louis of this vicinity. Small amounts of fluorspar occur in cavities in the rock, and there are several well-developed veins of calcite, the more prominent ones being represented on the map.

The central portion of the area is underlain by a broad belt of Chester formations trending northeast and southwest. These are in part in faulting contact with each other. Only the Ste. Genevieve limestone is mapped separately. The beds have a very gentle dip to the northwest, the highest beds noted being in sections 30 and 31.

The Mansfield sandstone occupies the northwestern corner of the area, and the irregular boundary, the presence of outliers, and the absence of faulting phenomena indicate that it rests upon the Chester with a normal erosion contact.

Igneous rocks outcrop at three points along the Ohio, cutting the St. Louis and Ste. Genevieve limestones. There are two other doubtful occurrences known.

The veins occur along fault planes having in most cases a northeast-southwest trend and falling within a single vein system crossing the area from section 8 to section 21. The area has up to the present proved the most productive in the whole district, but this may have been due as much to the nearness of the mines to the river as to the size of the ore bodies.

Fairview mine.—The first discovery of fluorspar in place and the first attempt to mine it seem to have been made upon the property now owned by the Fairview Fluorspar Company. There are several veins on the property, and ore is reported to have been discovered in 1842. No attempt seems to have been made to operate until 1862, when the Good Hope shaft was started. From that year until 1874 the work was practically continuous, the ore being smelted as well as mined on the property. Three successive smelters were built; two were destroyed by fire, and the third was torn down about fifteen years ago. The dumps of fluorspar which accumulated during these years when the lead alone was of value were worked up and sold in the years 1889 and 1890. From 1891 to 1895 the property was operated under lease by the owners of the Rosiclare mine, and a large tonnage of spar was disposed of. The Good Hope vein is now being reopened, and in the course of the present survey a number of the old stopes on this vein were visited. Since the reopening of the mine had only begun at the time it was visited, the following notes are based to some extent upon the published descriptions of J. G. Norwood[a] and S. F. Emmons[b] and an unpublished report on the property made in 1884 by Messrs. Anton, Eilers and R. W. Raymond and courteously placed at the disposal of the Survey by the present manager, Mr. T. P. Bisland.

The Good Hope vein occurs along a fault trending N. 21° E. and dipping 79° 30′ NW. The hanging wall is composed at the surface of a coarse sandstone showing no pebbles and believed to belong to the Chester. The foot wall at the main shaft is the Tribune limestone, as determined by Mr. Ulrich. A short distance to the southwest a shaft near the sawmill shows the foot wall to consist of a sandy shale similar to that occurring normally some distance above the Tribune limestone. This would point to a cross fault between the two shafts with a downthrow to the south. The downthrow of the main fault is to the west. The amount of the displacement is unknown, but is certainly 100 feet and probably much more. The walls underground are marked by vertical striations near the main shaft and in the north drifts. In the south drifts the striations are at angles to the northeast. The hanging wall is sandstone or very sandy shale to a depth of 150 feet at least. The foot wall shows limestone at the surface and again at 210 feet, but a considerable portion of the wall between is unbroken, and sandy material occurs at a depth of 30 feet.

The underground workings show a clean, hard hanging wall. The foot wall is usually less well defined and is broken by a series of

[a] Geol. Survey Illinois, vol. 1, 1866, pp. 366–372.
[b] Trans. Am. Inst. Min. Eng., vol. 21, 1893, pp. 31–53.

splits running off from the main vein. These have a course about N. 39° E. The old working extends to a depth of 213 feet, and drifts have been run in both directions at depths of 30, 60, 135, 160, and 210 feet. At present such of these stopes as can be entered show considerable bodies of clear fluorspar, mainly white, but with subordinate amounts of purple. In the fluorspar are small bunches of galena and blende. Minor amounts of pyrite and chalcopyrite occur and stibnite and jamesonite are reported. While the sulphides occasionally occupy distinct veinlets or occur in definite bands, they are more commonly completely intergrown with the spar. Calcite is also extensively developed, especially in the foot wall. No distinct crustification indicating a definite order of deposition of the various minerals can be made out, and there are no satisfactory evidences of differences in the character of the ore body at different levels. Certain of the old stopes showed chambers of considerable size, 15 to 16 feet wide, 20 to 25 feet high, and 40 feet or more long, with roof and face of fluorspar. In view of the fact that the property was formerly worked for galena alone, these chambers corroborate the statements made by Norwood and others as to the large size of the bodies of lead ore formerly found. Mr. Eilers estimated that at the time of his visit there was in one stope a body of ore 20 feet wide, 20 feet high, and 50 to 60 feet long, which would run 10 to 15 per cent galena. At the same time another stope 138 feet long was yielding ore which the owners stated ran 13 per cent of dressed galena. At present there are no considerable bodies of galena in sight, as all available ore of that kind had evidently been removed before mining stopped. It has been estimated, however, that there are reserves of 25,000 tons of fluorspar in the ground now open.

From the main shaft the vein has been opened a distance of approximately 150 feet in each direction. To the northeast, however, the vein has been mined through a number of other shafts up to the boundary line of the property, and practically continuous stoping has been done from the Fairview to the Rosiclare shaft. While the ore body is thus continuous from one mine to the other, the recent work indicates that the two mines are on separate fault planes. If the Rosiclare vein be projected to the southwest on an accurate basis it passes through one, at least, of the shafts which mark the Anderson Well vein, the first to be discovered. The course of the latter as generally given in N. 3° E., while the Rosiclare vein runs N. 18° E. (true). Since, however, the Anderson Well vein was never worked, not much importance is to be attached to the early determination of its course.

Rosiclare mine.—The Rosiclare mine has probably the longest record of nearly continuous production in the district. It is also the

deepest, the shaft now being down 300 feet, and for many years it was the only important producer of fluorspar. It is located about a half mile back from the Ohio and slightly farther from the Fairview mine. As already stated, it is believed to be on a different vein, though the ore body continues from one mine to the other.

The hanging wall consists of the same sandstone as at the Fairview. Samples taken from below the surface show that it has been altered to a hard quartzite by the deposition of silica between the sand grains. The foot wall at the bottom of the shaft is a fine-grained "plucky" limestone, which Mr. Ulrich considers to be probably St. Louis. At the surface the foot wall is not exposed, but from general relations it is presumed to be Ste. Genevieve. At a shaft across the road and to the northeast of the main working shaft, the dump shows fragments of limestone of possibly Tribune or Birdsville age, but it is impossible to determine the relations. Still farther to the northeast sandstone covers the whole surface.

The shaft is 300 feet deep, and development has been carried both to the northeast and to the southwest with underhand stoping. The vein is vertical and the walls where uncovered are well defined. The hanging wall is extensively exposed and shows numerous striations, which are horizontal. The foot wall is usually covered by a thick body of calcite.

The vein stuff consists essentially of fluorspar and calcite, with minor amounts of lead and zinc sulphide and occasional specimens of pyrite and chalcopyrite. Near the hanging wall there is ordinarily a band 1 to 2 inches thick of the sulphides, but they also occur throughout the fluorspar and intimately mixed with it. On one specimen of the blende a greenish-yellow material suggestive of greenockite (cadmium sulphide) was observed, and a small flake of native copper was also seen. The sulphides occur intimately intergrown and also intergrown with the gangue minerals. Along water channels the blende is occasionally altered to zinc carbonate, and in druses crystals of quartz occur frequently. No special order of deposition of the sulphides can be made out, and no differences in character with depth are apparent, either in them or in the fluorspar. The fluorspar occurs in great thickness and makes up the greater portion of the vein. This is usually 10 to 12 feet wide, but stopes 26 feet wide are now open. The whole face of such a stope is made up of practically clear fluorspar, with some intergrown calcite, particularly toward the foot wall. Ordinarily the calcite occurs for the most part back of a facing or fault plane, showing striations and separating the cleaner fluorspar from the mixed spar and calcite. A thickness of 14 feet of the latter between this facing and the true limestone foot wall has been observed.

The vein shows numerous slips and minor fault planes between the main walls. These seem to represent post-mineral fracturing, though the main facing mentioned above would more probably represent an original foot wall, back of which fluorspar and calcite have metasomatically replaced the limestone. Within the vein the fluorspar shows in great clear banded surfaces resembling onyx. If these represent replacement of the limestone instead of cavity filling, the material has so completely recrystallized as to destroy all evidence of the bedding. Running through the ore body are druses and channels lined with crystals of fluorspar, calcite, and quartz. These are water channels and seemingly carry surface oxidizing waters, as is shown by their action on the zinc and iron sulphides. The whole of the workings are below water level, and approximately 75 gallons per minute are pumped in ordinary seasons. In wet weather this amount is materially increased.

Blue vein.—Northwest of the Rosiclare mine and on the property of the Fairview Fluorspar Company is the Blue vein, one of the first known in the district. Norwood describes it as 6 to 11 feet wide, with a sharp dip to the east and a course N. 29° E. He also mentions a cross vein, about 100 yards to the west, with a course N. 35° E. and a thickness of 3 feet. Neither of these veins has been worked for some time, and at present the dump shows only fragments of sandstone, shale, fluorspar, calcite, galena, and blende. The vein took its name from the quantities of blue fluorspar found in it.

Daisy vein.—A shaft on this vein was open at the time of Mr. Emmons's visit to the region, and he speaks of it as being 40 feet deep. The vein is said to have been very productive, but the workings have been abandoned for some years. At present fluorite may be seen on the dump and in small bunches attached to the quartzite foot wall. The vein has an apparent course N. 38° E. and a dip to the northwest of 69°. The hanging wall is apparently composed of shale, and there are no fragments of limestone on the dump. These relations suggest that the Daisy vein marks the position of the fault supposed to cut off the Cypress sandstone from the Birdsville formation, and to account for the absence of the Tribune limestone over most of the area.

A short distance northwest of the Daisy vein a fault is indicated on the special map as marking the boundary between the Ste. Genevieve limestone and the sandstone. There is no direct evidence of faulting here, but the abrupt termination of the sandstone along a sharp line is very suggestive of it.

Clement vein.—This vein occurs along the contact of the Ste. Genevieve limestone to the east and the higher Chester beds to the west. There seems, however, to be but slight faulting. The vein has a

general course N. 45° E. Near the fault and on the hanging-wall side the sandstone is tilted to an angle of 44°. The old Eureka workings, which were open at the time Mr. Emmons visited the area, were on this vein. A large amount of spar was shipped from them and the vein was proved to a depth of 80 feet.

At present the Marion Mineral Company is sinking a shaft farther to the northeast. The vein stuff consists of brecciated limestone with purple and white fluorspar crystallized with calcite. In druses the spar, calcite, and some small quartz crystals are crystallized together.

In the vicinity there are several faults and a number of small prospects. These are represented on the map. One of the most interesting of the faults is east of Big Creek and is locally known as the "Copper vein." It has a course N. 37° W., and shows limestone on both walls. At the surface is a reef of highly silicified limestone projecting above the ground. The vein is about 6 feet wide and consists of a breccia of limestone cemented by calcite and with some crystals of quartz. Stains of malachite occur, but no other metallic mineral was observed. The surface outcrop shows cavities left by the leaching out of some flat, tabular crystals, possibly barite. The vein is of interest because of the unusual character of its contents and its course, nearly at right angles to the others discussed. It has not, so far, proved of any value and seems to belong with the barren calcite veins near by.

HICKS AREA.

Résumé of geology.—The Hicks area includes the greater part of a small structural dome in which beds from the Devonian black shale to the Mansfield conglomerate are exposed. The mines are confined exclusively to the area of outcrop of the Chester formations, and to a very notable degree the ore is developed in or near the Ste. Genevieve limestone (Pl. III).

Empire mine.—The Empire is perhaps the best known of the mines back from the Ohio River. It has been worked at different times for a number of years and has made several shipments. In the vicinity there are a number of faults which for the most part seem to be of small throw. The more important ones only are represented on the accompanying map. The Empire vein follows a fault with a course N. 48° E. and a dip 73° SE. At the shaft limestone is found on both sides of the vein, and the amount of faulting does not seem large. The fault is normal, with downthrow to the east. This is indicated by the upturning of the shale partings in the beds of the hanging wall and by the general relations of the rocks. In the field north of the mine the Rosiclare and Ohara members of the Ste.

Genevieve limestone may be identified, and near the shaft sandstone, presumably Cypress, rests on the limestone with a normal erosion boundary. In some open cuts, and in the bed of the stream crossing the vein northeast of the shaft, limestone may be seen on both sides of the fault, and while the identification of the hanging wall is not positive the rock is apparently the Ste. Genevieve. Still farther to the northeast shaly and cherty beds take their place. Mr. Ulrich identifies them as probably Birdsville, and this would require a small block of higher strata faulted down to the general level. This block is indicated on the map, but with no pretensions to accuracy of outline.

From the shaft the Empire vein has not been traced far to the southwest, the presence of sandstone on both sides making surface identification somewhat uncertain. Fluorspar is, however, reported from its probable extension in section 34. From the shaft south the sandstone seems to be cut off to the east by a second fault extending from the Empire to the Hubbard shaft, and at a number of points along this line fluorspar has been found.

The workings of the Crystal Fluorspar Mining Company consist of a large open cut and a shaft sunk on the vein, which was 127 feet deep when visited, and has since been continued to a depth of 160 feet. In the open cut a wall of solid white fluorspar was at one point exposed, dipping to the east parallel to the hanging wall of the vein. Against it and in the V-shaped angle between it and a perpendicular plane to the surface was a body of zinc carbonate. This is said to run 38 to 40 per cent of metallic zinc, and has the appearance of being of fair grade. The amount exposed was not large, and the total amount present is wholly unknown. It is associated with residual clay, and seems to represent surface concentration against the hanging wall of the vein.

In the shaft a vein usually from 6 to 10 feet wide and with well-developed walls is shown. The vein matter consists of brecciated limestone cemented by fluorspar and calcite intimately intergrown. In this matrix galena, blende, pyrite, and chalcopyrite occur, the two first named being frequently in considerable abundance. The sulphides, particularly the blende, show a tendency to replace the fragments of limestone and also to some extent the wall rock. Occasionally they are segregated in a distinct band, which in one place is as much as 4 inches thick and occurs along the hanging wall. It is rather noticeable that the sulphides are for the most part very fine grained and are intimately associated with the wall rock and the gangue. The dark shaly material found in the hanging wall is rather widely distributed through the breccia.

The fluorspar occurs largely interbanded with calcite, but a band of clear spar from 1 to 4 feet wide is found almost continuously from the top to the bottom of the shaft, either on foot wall or hanging wall. A total thickness of 6½ feet is reported from one point in the shaft. The workings are now some distance below water level. There are no marked differences in the character of the ore at different levels except the presence of the zinc carbonate in the open cut, and there are no evidences of secondary enrichment or redistribution of the ores. As no drifts have been run and no stopes opened, it is impossible to make any estimate of the amount of ore opened. A considerable amount of the fluorspar seen could be shipped as mined, but to save the zinc and lead and the remaining portion would require careful milling, with rather fine crushing and concentration.

In the field north of the mine, as well as the fields to the south, fluorspar occurs in the soil at a number of points, but the development work is not sufficiently advanced to show the character and relations of the veins. In the SW. ¼ NE. ¼ sec. 34 the hillside is literally covered with clear glassy spar in a great variety of beautiful colors. A number of shallow pits here show its wide distribution.

Hubbard shaft.—In section 34, southwest of the Empire, is the shaft being put down by Mr. H. B. Pierce and his associates of the Grand Pierre Mining Company. This shaft is about 60 feet deep and in limestone, apparently the Ste. Genevieve. This was encountered at a depth of 12 feet. In an open cut near by are sandy beds belonging to the higher formations. The shaft seems to be on an intersection of two or more crevices, the main one, as shown in the open cut, having a course N. 45° E. The crevice is vertical and the amount of faulting does not seem to be great. In the shaft the vein was obscured by the presence of red surface clay, but brecciated limestone with a matrix of calcite and fluorspar was made out. A short distance to the northeast, near the creek, is a reef of brecciated quartzite with some fluorspar in the cementing material. In a trench cut across the reef the beds are seen to dip to the southeast. At a number of points over the low ground adjacent large quantities of "glassy" spar have been dug from shallow depths. The spar is variously colored and is so widely distributed as to indicate the presence of a few cross fractures.

Big Joe mine.—In section 27, northwest of the Empire mine, spar has been found at a number of points. At the Big Joe the surface formation is sandstone, probably belonging to the Birdsville formation. The vein has a course N. 15° E. and has been developed to a depth of 60 feet. There are apparently two veins, with a block of quartzitic sandstone between. At a depth of 20 feet the quartzite gives place to black sandy shale, which occupies the space between

two veins of fluorspar, each 8 to 12 inches thick. Apparently the shale has been thrust upward, or rather both the foot wall and hanging wall of the vein as a whole have moved downward, leaving the shale as a wedge between the two walls. There are small veins of galena one-fourth inch thick which come down to the shale and are there cut off abruptly. It is reported that 200 pounds of lead were shipped from a surface pocket at this shaft. A small amount of blende and occasional pieces of pyrite have been found in the vein. It is said that the last work done on this property showed fluorspar, calcite, and galena distributed pretty well over the bottom of the shaft.

The same vein, presumably, has been opened on the ground south of the Big Joe and has yielded several hundred pounds of lead ore. There are there, as at the Big Joe, parallel crevices, and fluorspar, calcite, galena, and blende occur, intimately intermingled in crevices in the quartzitic sandstone.

Two small prospects have also been opened near Mr. Jesse Crab's house, not far from the Big Joe. They show the usual association of ores, a small vertical vein about 2 feet thick crossing the quartzite.

In the northeast quarter of the same section a vein 2 feet or more in width of deep-purple spar shows in the bed of a small creek. The vein has a course N. 58° E. and lies between the St. Louis and Ste. Genevieve limestones. No work has been done on this vein, but the spar has the appearance of being very clean.

Hutchinson mine.—In SE. ¼ SW. ¼ sec. 22 Mr. James Hutchinson has an open pit, in which are a series of parallel crevices running through the sandstone with a course about the same as at the Big Joe. The crevices are vertical and narrow. White, purple, and green fluorspar occur, with a minor amount of galena.

Rainey mine.—In SW. ¼ SE. ¼ of the same section (22) is an open pit located on the contact between the Ste. Genevieve and the Birdsville formations. Limestone shows on both sides of the pit, but in the hill above to the west is blue shale, and a short distance beyond sandstone occurs. There seems to be some slight faulting here, with downthrow to the north. The course of the vein is N. 25° E. The vein is 12 to 18 inches wide and shows fluorspar, galena, and blende. Minor amounts of zinc carbonate have been formed by the alteration of the blende.

Baldwin mine.—This is located in SW. ¼ SW. ¼ sec. 23, and consists of an open cut about 10 feet deep. It exposes a vertical vein about 6 inches wide cutting the Ste. Genevieve limestone and having a course about N. 40° E. The limestone is slightly brecciated, but the bulk of the vein stuff consists of purple fluorspar and white calcite, with minor amounts of galena and blende.

Hicks mine.—This is in the same section as the Baldwin and is supposed to be on a continuation of that vein. When visited it was a prospect only, the fluorspar having been located by means of a post-hole digger. A body of clear spar somewhat over 2 feet thick was indicated.

In another portion of the SE. ¼ NW. ¼ sec. 23 two small open cuts show the presence of a 3-inch vein of purple spar, with considerable calcite, cutting across the Ste. Genevieve limestone with a course N. 20° E. Slickensides indicate some faulting, and the downthrow is apparently to the west.

Hamp mine.—On the northeast flank of the Hicks dome is a second group of prospects, of which the Hamp mine is the most important yet developed. This mine is on a well-developed fissure cutting the Ste. Genevieve limestone with a course N. 60° E. There seems to have been very little displacement, since the Rosiclare sandstone member of the formation occurs at nearly the same elevation on both sides. The vein dips SE. 68° and crosses the beds on both dip and strike, the dip of the strata being 10° NW. The vein consists of very clean "ribbon" fluorspar, mainly white in color, but with some purple near the surface. There is very little calcite developed with it. Some galena is found and very subordinate amounts of blende. The property is being developed by two shafts, the deeper being at last accounts 61 feet down, and showing at the bottom 6 feet of clear white fluorspar.

East of the Hamp mine there are a number of small prospects showing spar, as indicated on the map. None of these have been developed enough to make clear the relations of the ore bodies. Northwest of the area also (sec. 11, T. 11 S., R. 7 E.), on the Wright land, some prospecting has been done in an area of complexly faulted and slightly folded rocks.

SCATTERED MINES IN HARDIN COUNTY.

General statement.—At a number of points throughout the county and outside of the areas specially mapped there are occurrences of spar and lead, and at a few places some mining has been carried on. As many of these places as possible were visited in 1903, and brief notes on a number of them are given below. The largest number of these mines is near Eichorn, which is located in sec. 11, T. 12 S., R. 7 E. The Pell, Stewart, Cook, Oxford and Watson, Parkenson, and Gordon are in this vicinity, the two last named being in Pope County. At Lead Hill, north of Cave in Rock, mining has also been carried on at a number of points. In the country back of Lead Hill, extending to Rock Creek, are a number of prospects, including the Showalter, Patton, and a second Eureka. This enumeration does not exhaust the list, but includes most of those personally visited.

Pell mine.—This property is located in sec. 24, T. 12 S., R. 7 E., on Threemile Creek, near St. Joseph Church. There is a well-equipped hoisting plant and concentrating mill, not now in operation and said to have been run but a short time. The shaft is reported to be 95 feet deep and sunk on the vein, which apparently dips to the east. The course of the vein seems to be about N. 20° to 30° E. The dump pile consists mainly of limestone, with some sandstone. The vein stuff evidently includes brecciated limestone, with calcite, fluorite, galena, and blende acting as the cementing material. The sulphides occur also in cracks in the limestone, and to some extent disseminated in and replacing the rock. The stock pile shows some fluorite of good grade, and a small amount of zinc carbonate with occasional stains of malachite. The ore bins show a fairly clean grade of rosin blende and some well-cleaned galena. Financial difficulties and dissensions in the management are given as reasons for the property being idle.

Stewart mine.—This property, operated by the American Mines Company, is located northwest of the Pell, in section 14. Several small shafts have been sunk on a nearly vertical vein running N. 20° E. between Cypress sandstone on the east and Ste. Genevieve limestone on the west. This vein has been traced for about a half mile along its course, and where seen showed from 2 to 3 feet of purple and white spar with small amounts of barite and some small black quartz crystals.

Oxford and Watson mine.—This property is near the Stewart, in SW. ¼ NE. ¼ and NW. ¼ SE. ¼ sec. 13. A small prospect shaft has been sunk in the limestone, probably Ste. Genevieve, and near the sandstone. It has developed the presence of a breccia of which the fragments are limestone and the cementing material is mainly calcite. A few crystals of blende and galena were observed, but no considerable body of ore has been found.

Cook mine.—This is a small prospect shaft 70 feet deep about a half mile northeast of the Oxford and Watson. It is on the contact between the sandstone and limestone and shows considerable calcite and some fluorite in the north side of the shaft. At 56 feet the east side of the shaft was entirely occupied by red clay.

Parkenson mine.—This property is a couple of miles southwest of the Stewart and just across the line in Pope County (NE. ¼ sec. 27, T. 12 S., R. 7 E.). The country rock here is sandstone, presumably belonging to the Cypress formation, and while there has evidently been some faulting, it has not been enough to bring the limestone to the surface. The property was not in operation when visited, but the dump showed the presence in small quantity of fluorite, blende, and barite. The course of the vein seemed to be N. 30° E.

Gordon mine.—On the same quarter section and possibly on the same vein as the Parkenson is the Gordon shaft, also not being worked when visited. Here, again, the sandstone shows some brecciation, and fluorite, calcite, barite, blende, and galena occur. The barite and blende seem to be especially abundant and are apparently of good grade.

Lead Hill.—About 3 miles from the river, at Cave in Rock, there is an abrupt rise of 80 feet and a mural escarpment fronts the irregular plain developed over the area of St. Louis limestone. At the foot of this escarpment and parallel to it is a fault which may be traced somewhat south of east for nearly 3 miles. Along this escarpment, particularly in sections 3 and 4, T. 12 S., R. 9 E., mining has been carried on for a number of years, and formerly enough lead was taken out to give its name to the locality.

In 1903 the Cleveland-Illinois Fluorspar Company was operating a mine about on the line between sections 2 and 3. The company was working a bedded or sheet deposit in the Fredonia member of the Ste. Genevieve limestone and just under the Rosiclare sandstone. A number of short drifts were run into the hill, and the workings were conducted on a modified room-and-pillar system. The ore body varies in thickness from 18 inches to 6 feet, thinning as the workings extend into the hill. The vein stuff consists to a minor extent of brecciated limestone, but for the most part of interbanded limestone and fluorite with minor amounts of calcite and galena. At the top of the ore there is a band of green sandy shale a few inches thick, and the fluorite extends into this between the laminæ. Breccia is only locally developed, and banded limestone and fluorite, such as is illustrated in Pl. V, is more common. In this specimen the individual bands of purple and white fluorite are one-half to three-fourths of an inch thick, and are separated by layers of equal thickness made up of very impure limestone containing notable quantities of silica and iron oxide. This banding represents horizontal bedding, and the fluorite has evidently been introduced along the stratification planes, uniting with the calcium of the limestone and excluding the impurities. These were partly, no doubt, carried off, but also in part remain trapped between the growing crystals of fluorite and in the bands of unreplaced limestone.

These relations are perhaps made clearer by the photomicrographs of Pl. VI. In *A* is shown, in natural light, a portion of one of the fluorspar bands. Traces of bedding may be observed, and the iron oxides and other impurities are so arranged as to mark the outlines of granular material, presumably the original calcite.

In *B* the same section is shown between crossed nicols. The fluorite appears entirely black, while the small points of light indicate

INTERBANDED FLUORSPAR AND LIMESTONE FROM LEAD HILL.

PLATE VI.

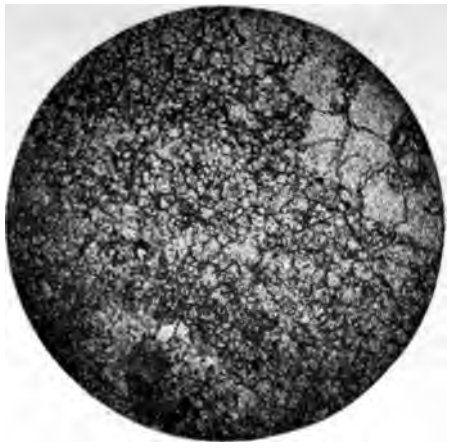
PLATE VI.

PHOTOMICROGRAPHS OF FLUORSPAR BANDS IN ORE BODY AT LEAD HILL.

A.—Natural light, showing granular outline of original calcite particles.

B.—Polarized light, showing complete penetration of original calcite (white) by fluorine now forming fluorspar (black).

C.—Natural light, showing preservation of original bedding plane in clear fluorspar.



A

B

C

PHOTOMICROGRAPHS OF FLUORSPAR BANDS IN ORE BODY AT LEAD HILL

the presence of minute grains and crystals of calcite and quartz. The bedding may still be made out, but the outlines of the calcite crystals are completely obscured. The very intimate association of the calcite and fluorite are notable and indicate the entire penetration of the rock by the fluorine. The calcite of the large crystal in the lower portion of the field has been partly replaced by fluorite, the bounding planes being evidently determined by the cleavage planes of the calcite. The calcite is under strain, as is indicated by the undulatory extinction

In *C* a view is shown, in natural light, of the central portion of one of the bands of fluorite. Running through this band is an irregular plane, which might readily be mistaken for such a surface as is produced by the interlocking of crystals making up the comb structure of ordinary banded ore deposits. In this case, however, the irregularities of the line bear no relation to the optical orientation of the crystals, and the line is furthermore of the exact character common in sedimentary beds between individual layers, particularly where the beds have been under slight pressure, so as to produce stylolites.

The above evidence warrants the conclusion that in this ore body the fluorine has been introduced along horizontal bedding planes and that fluorite has metasomatically replaced the calcite of the limestone, producing a banded structure without crystallization in free spaces. On the whole it forms an interesting and typical example of the phenomenon of pseudo-crustification, discussed some years ago by Mr. Emmons.[a] In this case horizontal bedding planes rather than vertical shearing planes are concerned.

With the metasomatic replacement of the rock there has been also some free growth of crystals wherever space has been available in druses or the brecciated rock. Very beautiful specimens of golden, purple, and white fluorspar occur, showing the cube with occasional modifications by octahedral faces.

The introduction of the fluorine solutions was doubtless from the main fault along the foot of the hill, and occurred before the development of the present topography. The calcareous sandstone forming the Rosiclare member of the limestone was the particular localizing agent, as it forms a firm roof over the mine, and, being of unusual thickness, 25 feet, was a competent stratum under mild stresses. This had the effect of opening up the upper bedding planes of the limestone and allowing slight local brecciation, so as to afford entrance to the solutions.

The main fault at the foot of the hill is complicated by the presence of a number of minor faults. Along one of these near the mine is an

[a] Structural features of ore deposits: Trans. Am. Inst. Min. Eng., vol. 16, 1888, pp. 804–839.

important development of barite, which is particularly interesting in view of the absence of that mineral in the ore body on the hill. The relations of the two were not made out.

South of Lead Hill, near Cave in Rock, and between that place and Elizabethtown, there are a number of faults and some prospecting has been done. So far as could be learned no considerable bodies of ore have been found.

Eureka mine.—North of Lead Hill the rocks are faulted and disturbed at a number of points and prospecting has been carried on, without, however, so far as known, developing any ore bodies of consequence. A possible exception is the old Eureka mine, not the same as that near Rosiclare (sec. 23, T. 11 S., R. 9 E.), which is said to have yielded several tons of galena. The works are now abandoned, but at the shaft a fault plane running N. 60° E. may be seen separating sandstones believed to be Mansfield to the north and Chester to the south. The dump shows small pieces of galena, fluorspar, and calcite.

SCATTERED MINES IN POPE COUNTY.

General relations.—Much the larger portion of Pope County north of Bay Bottoms is underlain by sandstones of the Mansfield and Chester formations. The general absence of the Ste. Genevieve and lower limestones makes it difficult to recognize faulting, and so, while disturbances of the strata have been noted at a number of points and prospecting is widespread, relatively little has been determined with regard to the stratigraphy of the region. There is one belt of mines extending from the vicinity of the Empire mine to the "Old Clay diggings" of the Pittsburg Mining Company near Raum. A second, or possibly a continuation of the first belt, includes a number of prospects near Allens Spring. Near Golconda there are a few veins and some prospecting has been done, and northeast of town are the Parkenson and Gordon mines, already discussed. Near Bay City considerable lead ore is said to have been mined. These mines and prospects will be discussed in the above order.

Pittsburg mine.—The Pittsburg Mining Company has sunk two shafts and driven one tunnel into a narrow belt of limestone outcropping in the general sandstone region near Raum. The limestone is dark, flinty, and not very fossiliferous. It seems to be of St. Louis age. It outcrops in a belt about 200 feet wide, having a general course N. 35° E., and is said to be traceable for several miles. The sandstone to the northwest, at least, is probably Mansfield. That to the southeast is of undetermined age. The limestone is much broken and there are considerable bodies of breccia. Galena and blende occur in small veinlets through the limestone and in the

matrix of the breccia. They are associated with calcite and white and purple fluorite, which form the main cementing material. The blende is a bright rosin "jack," and the company is now reported to be erecting a mill for concentrating the ore.

Near the works is the kaolin pit from which the property takes its local name, "Old Clay diggings." The pit has been abandoned for a half century, but its size indicates that considerable bodies of kaolin were shipped. The kaolin occurs apparently on the contact between the limestone and the sandstone, which, as now exposed, has weathered to a bright-red color. The origin of the kaolin is unknown. No igneous rocks have been found in or near the mine.

McClellan mine.—Northeast of the Pittsburg mine (section 11) limestone is again seen, but its age was not determined. The general country rock is sandstone. A shaft 40 feet deep has developed evidences of faulting and a body of very clear fluorspar 6 to 7 feet thick. No sulphides were noted. There seems to be a system of veins running from N. 15° E. to N. 35° E. These mark fault planes, some of which bring limestone to the surface and some do not.

In an adjacent section (3) there is a well-developed quartzite reef, marking a fault plane in the Chester sandstone and shale. A small body of zinc carbonate was found near it.

Luella mine.—Southwest of the last-mentioned locality (sec. 10, T. 12 S., R. 6 E.) and apparently on the same belt of faulting the rocks are disturbed and fluorspar is introduced along the sides of an infaulted block of limestone. A considerable amount of white spar appears here at the surface, some of which seems to be sandy. There is also a pit showing a small body of kaolin, but the relations could not be determined owing to the limited amount of development.

Taylors Spring.—Comparatively little prospecting has been done in the region about Allens Spring and Rock, though faulting is common and float mineral has been found at several points. Near Taylors Spring (sec. 31, T. 12 S., R. 6 E.) the sandstone has a dip of 22° S., strike N. 55° E., and shows quartzitic facies. In the field near by small pieces of fluorite and galena have been found.

Moore mine.—On the Moore farm, near Taylors Spring, an open cut has been made in sandstone and shale, and small pieces of fluorite and galena have been found.

Wright mine.—In section 3, T. 12 S., R. 5 E., a small shaft has been sunk in shales and sandstone, probably of Birdsville age. The rocks dip at high angles, 30° to 47°, and in conflicting directions in this vicinity, and evidently have been considerably disturbed. Calcite and pyrite were the only minerals found in sinking, and no well-developed vein was located.

Southwest of this work, in section 9 (NE. ¼ NE. ¼), the beds are again disturbed, and belts of Birdsville of considerable width are

given high angles of dip. A number of prospect shafts have shown some brecciation of the rock and the presence of calcite as a cementing material.

Golconda prospects.—About a mile south of Golconda, on the river bank, faulting has brought the Mansfield sandstone of the bluffs into contact with the Chester formations. Parallel to the fault the sandstone is sheeted or sheared and a minor amount of barite has been introduced. No other minerals occur.

West of Golconda the Chester comes in abruptly, replacing the Mansfield, and there seem to be several minor parallel faults and crevices. In one of the latter, showing in the first railway cut west of the town, is the Gilbert dike, which was prospected for mineral to a depth of 70 feet in 1903 without favorable results.

Bay City mine.—Near Bay City the rocks are broken by fault planes presumed to represent the Rosiclare-Fairview system of faulting. Along these planes fluorite, galena, and blende have been deposited, and an effort is being made to mine them. The Black mine is located in section 26, T. 14 S., R. 6 E., on a low hill rising about 25 feet above the Ohio River bottom land and cut off from the main bluff by a low col. Near the old shaft there are clear evidences of faulting in the sandstone which forms the surface material. The dump shows a brecciated limestone cemented by calcite and fluorite and carrying galena and blende. A small amount of zinc carbonate also occurs. The vein dips to the west, and a new shaft was being sunk to intersect it. In the hillside near by there is a narrow belt of limestone running about parallel with the fault upon which the ore has been found.

MINES IN SALINE COUNTY.

General relations.—Near the southern border of Saline County, not far from the Pope County line, small quantities of galena and fluorite have been found and some prospecting is going on. The country is rugged, the area including a part of Karbers Ridge. The rocks consist mainly of Mansfield sandstone, with subordinate areas of the later coal measures and some infaulted blocks of Chester limestone.

King and Fergusen mine.—This property is in section 21, T. 10 S., R. 7 E. The surface rocks consist mainly of sandstone, with subordinate amounts of black shale and limestone. They have been considerably disturbed and dip occasionally at high angles. There are three shafts. At the first the beds strike nearly north and south and dip 52° to the east. This shaft has been sunk on a thin bed of black shale, and there is apparently no displacement, though a minor amount of dip faulting may be present. Barite and fluorite are found in small amounts crystallized together in broken quartzitic

sandstone. There are a few small crystals of galena. Calcite seems to be entirely absent. In the second shaft a limestone is present and small amounts of galena and fluorspar show. In the third, located farther south, near a contact of limestone and sandstone, small amounts of galena, pyrite, and fluorspar occur in cracks in the limestone.

Big Four mine.—On the Miller land, section 32, a shaft has been sunk 30 feet in Chester limestone. This rock is apparently in place and undisturbed, though near it pieces of brecciated limestone cemented by calcite were picked up, and in the same vicinity there are small pieces of blende and evidences of faulting. In general it may be said that in the vicinity small quantities of the sulphides and of fluorspar are widely disseminated and the rocks are faulted and broken in a manner favorable to ore deposition. At the time the area was visited, however, no considerable bodies of ore had been located. Later prospecting is said to have given more encouraging results.

GENESIS OF THE ORES.

It is impossible in the present condition of knowledge to make an exact and final statement as to the origin of the ores of this district. The best that can be done is to indicate certain alternative hypotheses and to discuss their possible conflicts and agreements. In view of the unusual character of the ores and the interest attaching to them, it is believed worth while to do this, even though it be admitted at the outset that the explanation offered is founded on hypothesis, though in accord with the facts as known.

ORIGINAL SOURCE OF MATERIAL.

The ore bodies represent concentrations of material normally present in rocks in a disseminated form. The minerals entering into their composition must have come either from the sedimentary rocks exposed at the surface and continuing for some depth below, or from deeper lying igneous rocks of which the dikes present at the surface represent offshoots. Neglecting calcite, pyrite, and other minerals widely distributed, attention may be concentrated on the rarer metallic sulphides—galena, blende, and stibnite—and on the fluorite. The discussion of their possible origin will be taken up in order.

ORE MINERALS.

The common ore minerals of this district, neglecting secondary and derived forms, are galena and blende. These sulphides of lead and zinc occur in both igneous and sedimentary rocks and are widely

disseminated. Large bodies in unaltered limestone are especially characteristic of the Mississippi Valley and they show throughout the world a tendency toward segregation in dolomite and limestone. The lead and zinc deposits found at other points in the Mississippi Valley, excluding those of southwestern Arkansas, are believed to represent concentrations from the surrounding limestone brought about by the activities of ordinary meteoric water. Specifically, it is believed that they represent material originally deposited in the dolomites of the Cambro-Silurian and later concentrated in their present situations.[a] The evidence for this will not be reviewed here. In certain particulars the ores of this district differ from those found elsewhere in the valley, and this raises a question as to the applicability to them of the theories worked out from a study of the others. These differences are as follows:

(1) The antimony occurring in connection with the lead is found elsewhere in this region only in southwestern Arkansas, where the relations are entirely distinct from those normal to the Mississippi Valley. The lead ores of the valley are always particularly free from antimony, so much so as to class them as soft ores in distinction from the western or hard ores.

(2) The fact that the galena is slightly argentiferous is also distinctive. The amount of silver present is not great, but is none the less large when contrasted with that found elsewhere in the region. The following analyses made by Messrs. Chandler and Kimball were published some years ago by Whitney,[b] and indicate the amount of this difference.

Analyses of galena from southern Illinois.

	Troy ounces silver per 2,000 pounds lead.
Roselare, Ill	9½
Massac County, Ill	1⅛
Mineral Point, Wis	3
Rockville, Wis	⅛
Marsden lode (near Galena), Ill	5/16

The amount of silver is small and its occurrence seems irregular, but that it is ever present to the amount indicated is striking. H. A. Wheeler has recently discussed this point in connection with the occurrence near Fredericktown, Mo., and in Algonkian felsites of a narrow vein of nonargentiferous galena.[c] He argues from this that the neighboring lead deposits in the limestone were deposited by ascending waters of presumably deep-seated origin. If it prove gen-

[a] Preliminary report on lead and zinc deposits of the Ozark region: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, pp. 23–227.

[b] Whitney, J. D., Geol. Survey Illinois, vol. 1, 1866, pp. 188–189.

[c] Wheeler, H. A., Eng. and Min. Jour., March 31, 1904.

erally true that the galena of the older rocks in this region is nonargentiferous, this would seem to emphasize the unusual character of the conditions under which such deposits as those of southern Illinois originated and would point to the improbability of the whole of the material entering into the composition of the ore bodies being derived from the normal rocks of the region.

(3) The marked development of fluorite in connection with the lead and zinc is wholly exceptional for this region. In none of the other lead and zinc districts has this mineral ever been noted, despite its showy character; and in the Joplin district the country rock, so far as Mr. Steiger's analyses go, fails to show a trace of fluorine. While any negative evidence derived from country rock is not considered strong evidence, it is at least suggestive.

(4) The presence of numerous and important fault planes and the association of the ores with them are peculiarly characteristic of this district. While faulting is not absent elsewhere, and, indeed, is believed to have a high significance as regards the genesis of the Joplin ores, it is nowhere as important as here, and in none of the other districts do the ores so persistently follow the fault planes. In this particular the ore bodies found here are more like those of the Western States than like those of the Mississippi Valley generally.

(5) The presence of igneous rock in the vicinity of the ore bodies is, so far as known, wholly restricted to this particular district.

These various facts point to the conclusion that, while it would perhaps be possible to consider the lead and zinc found here as being in the same category with that found elsewhere in the Mississippi Valley, the probability is that either its source was unusual or the conditions under which it was concentrated were entirely different from those prevailing elsewhere. The most notable peculiarities in each particular seem connected with the presence in the district of igneous rock.

GANGUE MINERALS.

The gangue minerals associated with the ore bodies of this district are those common in the Mississippi Valley, with the exception of the fluorite. Calcite, quartz, and barite are found in all the districts, though not in equal amounts. There is a striking and peculiar absence of dolomite, which elsewhere is a constant associate of galena and blende. Whether this absence is due to the derivation of the ores from the immediately surrounding rocks, which are nonmagnesian, or from some entirely new source, or whether the Cambrian and Silurian rocks underlying the district are here nonmagnesian, is uncertain. The greatest peculiarity of the ore bodies, however, is the presence of large quantities of fluorite. This mineral is somewhat

widely distributed, principally in metamorphic rocks. In the United States it occurs from Maine to Virginia in the Piedmont and Appalachian areas.[a] In the Western States it is not uncommonly found in small quantities in connection with metalliferous veins. In the Mississippi Valley it is exceedingly rare. At one or two localities in central Kentucky and Tennessee it occurs in nonmagnesian limestones. From Tennessee it is now being shipped. It is reported to occur in druses in the St. Louis limestone at St. Louis, and Mr. Ulrich has observed a few crystals in the Ste. Genevieve limestone at the type locality for that formation. With these exceptions it is not known to occur at any point in the valley, and it is entirely absent from all the lead and zinc deposits of the region, except those of this particular district and the small deposits in central Kentucky near Lexington.

Abroad the most important localities for the production of fluorspar are the north of England and certain Saxon mining localities in Germany. The English deposits occur in limestones of about the same age as those of southern Illinois, and in many particulars the occurrences are similar. This extends even to a close similarity in the dike rocks present in both districts. In Saxony the fluorspar occurs near Freiberg in veins and druses in gneisses, schists, and slates, cut by dikes of quartz-porphyry and by gabbro. It is associated with argentiferous galena, blende, stibnite, and many complex compounds not found in the Kentucky-Illinois district.[b]

Fluorine itself has been found in sea water, in boiler incrustations of ocean vessels,[c] and Dana found it in calcareous corals. It occurs in the bones of marine animals, and was found in small quantities in the manganese nodules brought up by the *Challenger* nets from a depth of 2,375 fathoms.[d]

From these notes it appears that fluorite may well be expected to occur in small quantity in limestones and other sedimentary rocks, but that its presence in unaltered limestones is very rare, and that the only important bodies of fluorite known and worked commercially are in limestones which have been intruded with igneous rock. Both Mr. Emmons and Mr. Tangier Smith have shown that the apparently unaltered limestones of this district contain small quantities of fluorine.

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[a] Dana, Mineralology, 6th ed., 1892, p. 163.

[b] Von Cotta, B., Treatise on Ore Deposits (Prime translation), 1870, p. 98.

[c] Pumpelly, Raphael, Geol. Survey Kentucky, 2d ser., vol. 2, pt. 8, p. 46.

[d] Deep-sea deposits, Report *Challenger* Expedition, p. 421.

Mr. Smith's analyses, made by Mr. George Steiger, of the United States Geological Survey, are quoted below.

Analyses of limestone from Kentucky and Missouri.

	I.	II.	III.	IV.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
MgO	0.15	1.48	0.19	1.33
CaO	5[illegible].6	51.75	49.94	52.24
F	.04	.10	.10	None.
BaO	None.	None.	.02	None.
Organic matter	Trace.	(a)	.....	(a)

a Doubtful trace.

I. Ste. Genevieve limestone from near View, Ky.
II. Ste. Genevieve limestone from near Crider, Ky.
III. St. Louis limestone from Crittenden County, Ky.
IV. Limestone from Shoal Creek, southeast of Joplin, Mo.

While there is always doubt attaching to the origin of these minute quantities of material, and it is impossible to make sure that they do not represent secondarily-introduced material, it would seem that the limestone is at least a possible competent source of the fluorite.

As a constituent of igneous rocks fluorite is common. It enters into the composition of a number of widely disseminated minerals, including the common variety of apatite, certain micas, and topaz. Of these the first two named occur in unusual abundance in the dike rocks of this vicinity, though it is not certain that the particular minerals found here are fluorine bearing. Analyses of the freshest dike rock available, made in the Geological Survey laboratory by Mr. George Steiger, gave the following results:

Fluorine in analyses of dike rock of southern Illinois and Kentucky.

	Per cent.
Downey dike, Rosiclare, Ill	None.
Mix dike, Golconda, Ill	0.13
Hard dike, Marion, Ky	None.

It is of interest to recall in this connection the fact that in even the most altered of the igneous rocks the apatite, presumably the mineral carrying the largest amount of fluorine, is fresh and unaltered.

Fluorine has commonly been observed in connection with volcanic outbursts, and fluorite is one of the most common minerals connected with volcanic rocks. At Cripple Creek, Colorado, and many other western camps it is abundant in intrusive and extrusive rocks of Tertiary age.

So far, then, the igneous rocks form a very probable source of the

fluorine, but the evidence that the material did actually come from them is weak. If it is of any such origin, it presumably was not segregated during the weathering of the rocks and, recalling the field evidence, there seems little connection between particular dikes and individual ore bodies.

PROCESS OF CONCENTRATION.

There are two broadly contrasted methods by which the present ore bodies may have been concentrated. The first is by the action of the normal meteoric waters of the region, which may here, as in other districts, have gathered the disseminated material from the country rocks into the veins. The second is by the action of heated waters, either originally meteoric or derived from the intruded igneous rock, or in part from each source. It is believed that the evidence points to heated waters having been the agency by which the ores were segregated and that they obtained an essential portion of their load from a large mass of lower-lying intruded rock, of which the dikes are the offshoots.

It has already been pointed out that the ore bodies show no sign of secondary enrichment, and apparently the surface waters now in the region can only operate to destroy rather than re-form the ore bodies. As compared with limestone, fluorite is relatively insoluble in cold water, though still more soluble than barite, which is very commonly concentrated by such waters. In the presence of an abundance of calcium carbonate in the surface waters mass action would demand that the waters largely exhaust their powers in working upon the country rock rather than the vein minerals. This seems to accord with the facts of the field, since the crystals of fluorspar in druses, which might be considered to represent reconcentration, are relatively rare, and, as has been seen, the sulphides, which are very delicate indices of the process of reconcentration, show no clear evidence of such action, but point rather to its absence. It is difficult to believe, therefore, that such waters have gathered minutely disseminated quantities of fluorite from the surrounding limestone and formed the veins as they now occur. It is also to be remembered that in other districts of commercial importance in the Mississippi Valley, where such waters have been shown to be effective, both the ores and the gangue differ in the important particulars already enumerated.

If it be held that the waters which formed the ores were heated waters, but that they derived their load from the St. Louis, Ste. Genevieve, and surrounding limestones, it may be pointed out that the normal tendency of heated waters rising along faulting fissures would undoubtedly be toward deposition and dissemination of material rather than toward its segregation. This would seem to indicate

that the waters were loaded before reaching these horizons rather than the reverse, and would make the association of the fluorspar with the Ste. Genevieve a matter dependent upon the precipitating action of the latter rather than the reverse. This does not exclude the possibility of minor contributions to the veins from the surrounding country rock, though it may be pointed out that it is to the lower-lying Cambrian, Ordovician, and Silurian rocks that one would look for any considerable quantity of lead and zinc if the general analogy of the other districts in the Mississippi Valley be considered important. This was indicated in an earlier general paper on the lead and zinc deposits of the valley.[a] The published data then available prove to have been somewhat misleading, and the analogy is now believed to be less close than was suggested.

It is probable that the unusual quantity of apatite in the dike material, and to a less extent the large micas, indicate a magma in which fluorine was present, and that this fluorine was given off to the underground waters during the period of cooling and consolidation of the underlying mass of rock.

The association of the minerals and the common phenomena of marked silicification of the hanging wall are interpreted as indicating deposition from heated ascending solutions carrying fluosilicates of zinc, lead, copper, iron, barium, and calcium. These are believed to have been broken up and precipitated by descending cold waters, which possibly also furnished the sulphur to combine with the metals, though it is not improbable that sulphur was an original constituent of the rising solutions.

ECONOMIC IMPORTANCE AND FUTURE OF THE DISTRICT.

SOURCES AND USES OF FLUORSPAR.

The Kentucky-Illinois district is not only the main American source of fluorspar, but is the only one from which spar reaches the general market. Since 1882 the district has produced 260,000 tons of spar, having a total value of $1,521,029.

There are no data for determining the production of the Illinois mines separately. For many years they produced practically all the output. Recently the Kentucky mines have been developed, and now are producing more than those north of the Ohio. In the following table are given the output and value of fluorspar in the United States for 1902 and 1903, the figures being taken from Mineral Resources of the United States, 1903.

[a] Van Hise, C. R., and Bain, H. Foster, Lead and Zinc Deposits of the Mississippi Valley, U. S. A., read before the Institution of Mining Engineers, London, 1902.

Production of fluorspar in the United States in 1902 and 1903, by States.

State or Territory.	1902.		1903.	
	Quantity.	Value.	Quantity.	Value.
	Short tons.		*Short tons.*	
Arizona and Tennessee	628	$6,872	275	$2,037
Kentucky	29,030	143,410	30,835	153,960
Illinois	18,360	121,532	11,413	57,620
Total	48,018	271,814	42,523	213,617

The spar is shipped in part by the Illinois Central Railway and in part on the Ohio River. Prices are fixed by Pittsburg quotations, less freight and commissions. At Pittsburg the American spar comes into competition with English and German material imported through New York. The American mines supply the western trade and about half of the Pittsburg demand. The importers control the eastern trade and determine prices at Pittsburg.

There are three main uses for fluorspar. The highest grade, running less than 1 per cent of silica, and white in color, is sold either ground or in lump, for use in the enameling, chemical, and glass trades. It brings the highest price, recent New York quotations being $8 to $10 a ton unground and $11.50 to $13.50 ground. The price at the western mines is about a dollar less per ton than the New York price, to offset differences in freight rates to competing territory. There is a limited market for this grade of spar, and it probably would not be extended much even at lower prices, since the amount used is determined by conditions wholly outside the cost of the spar. On the other hand, it is a question whether even a higher price could not well be obtained for this grade.

The second grade of spar is used in steel making, and is sold unground as lump or gravel. It includes colored spar and may run as high as 4 per cent silica, though mostly sold with a 3 per cent guaranty. It is demanded for open-hearth work because of the great fluidity which it gives the slag. At present at least 20,000 tons are used annually in this work, at a cost to the user of from $6 to $8 per ton. Importers have now a slight advantage in the Pittsburg market on this grade of ore. It is probable that when a steady supply of fluorspar at the present or slightly lower prices can be guaranteed in steel-making centers the market can rapidly be expanded, and this affords the most hopeful outlook for spar producers. In many ways fluorspar has advantages over other fluxing materials now used.

The lowest grade of spar, including all running over 4 per cent

silica, or spar mixed with calcite, can be used in foundry work, and while the price is and always must be low, there is possible an almost unlimited market. It is probable that systematic efforts to introduce the low-grade material into this trade would be highly beneficial to the industry as a whole. While there would be little profit in mining foundry spar, it would allow the production of No. 2 spar in quantity and at prices demanded by steel makers. With the exhaustion of bessemer grades of iron there will be an increased demand for fluorspar, though even now demand is ahead of supply for steel-making grades. Since at any increase in prices it becomes cheaper to use less efficient fluxes, it follows that while the output can be increased prices probably can not be much changed.

With these facts in mind it is seen that the fluorspar mines of the Kentucky-Illinois district will have for many years a large and growing market to supply. Their only competitors are the importers, and competition with them is mainly a matter of transportation costs. It is not certain that this competition will always be keen as now, since foreign producers have an important and growing trade outside the United States. Mines in the Rocky Mountain region and other Western States can not be expected to disturb the fluorspar market. Such fluorspar as occurs in connection with the ores of that region will probably always have a sufficient local market. The quantity present is not important in any western district yet described, and local smelters make an allowance for lime, which, entirely aside from the cost of transportation, is likely to prevent shipments of spar to the East.

FUTURE PRODUCTION.

The opinion already given as to the genesis of the ores indicates the belief of the author that they will prove permanent in depth to horizons below which they can not be worked because of increasing cost. The low value of the ore places a somewhat severe limitation upon the future depth of mining, and it is possible that this feature alone will in most situations preclude work to a depth greater than 1,000 feet. It is also possible that changes in the character of the country rock may influence disastrously the size and character of the ore bodies. It has been impossible to get any data on the character of the rock which occurs in this area beneath the Ohio shale. Normally a considerable thickness of dolomites and limestones would be expected to be present, but they may be absent, and it is not impossible that the supposed igneous mass occurs below the shale. In all the mines so far located in Illinois the shale lies 500 to 1,000 feet or more below present workings.

There are no data at hand for predictions as to change in character and richness of the ores with depth. Changes in the country rock may be expected to have an important influence, and so far the Ste. Genevieve and other Chester formations have proved most favorable. In the Illinois mines nothing suggesting rearrangement of the ores and secondary enrichment coincident with degradation of the surface was observed. At the Empire mine carbonates gave place to sulphides within the first hundred feet, and below that level no change was observed.

In the Kentucky mines a number of deposits of first-grade fluorspar are said to have given out or lost grade with depth. The significance of this fact is uncertain. Whether it is to be correlated with change in wall rock, or indicates only the usual irregular distribution of ore in depth as well as along a vein, is not clear. In no case was development carried on to determine whether the ore would come in again at lower levels. If it be true that the diminution in size of the ore bodies was related to topography rather than stratigraphy, it can only be stated that the best obtainable evidence in Illinois does not warrant the belief that the rule is universal. The character and size of the ore bodies certainly do not bear any constant relation to the present land surface.

In the light of these facts and the wide prospecting which has been going on in the district, little encouragement is offered to the hope of finding important bodies of lead and zinc on the northern side, at least, of the river, but it is believed that the fluorspar deposits afford the basis for an important and growing industry.

GUIDES FOR PROSPECTING.

Fluorite is such a distinctive and easily recognized mineral that it is not often overlooked. Its presence, or that of galena or blende, is usually sufficient to warrant careful prospecting for an ore body. Calcite, on the other hand, is so common that its presence is not often significant. The presence of faulting fissures may usually be recognized by the fact that rocks of unlike character are brought into contact along straight lines or by the presence of the quartzite reefs already discussed. To a less extent any disturbance of the strata is in this district probably connected with faulting. When a body of spar has been formed along a fault contact it should first be prospected by a few shallow shafts along the strike to determine its extent. That proving favorable, regular sinking may be undertaken with some confidence. In general it is to be remembered that the material is of low value and expensive installations are not warranted. While some lead and zinc may be saved in mining the spar, it is not thought that they are generally of first importance.

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DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

MINERAL RESOURCES OF THE ELDERS RIDGE QUADRANGLE, PENNSYLVANIA

BY

RALPH W. STONE

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., July 21, 1904.

SIR: I transmit herewith the manuscript and illustrations for a bulletin entitled "Mineral Resources of the Elders Ridge Quadrangle, Pennsylvania," by Ralph W. Stone.

This report describes an important coal and gas field, and particular attention is consequently devoted to those products, but the minor economic products of the area also are discussed in some detail.

Very respectfully,

C. W. HAYES,
Geologist in Charge of Geology.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

MINERAL RESOURCES OF THE ELDERS RIDGE QUADRANGLE, PENNSYLVANIA.[a]

By RALPH W. STONE.

INTRODUCTION.

LOCATION AND AREA.

The Elders Ridge quadrangle is located in central-western Pennsylvania. It extends from latitude 40° 30′ on the south to 40° 45′ on the north, and from longitude 75° 15′ on the east to 75° 30′ on the west. It includes, therefore, one-sixteenth of a square degree of the earth's surface, and covers an area of 227 square miles. It takes its name from a small village in its southern-central part, in Indiana County, almost on the Armstrong-Indiana county line.

About half of the quadrangle is in Armstrong County and half in Indiana County. The N. 36° E. line, which forms a portion of the boundary between the two counties, extends from the upper right-hand corner of the quadrangle to Kiskiminitas River in the lower left-hand corner. The portion of the quadrangle lying south of the river, about 5 square miles in all, is a part of Westmoreland County.

TRIANGULATION POINTS.

The exact location of the Elders Ridge quadrangle with reference to latitude and longitude is determined from certain high points, the position of which has been ascertained accurately by triangulation. There are four triangulation stations within the boundaries, and five near by, which give complete control of the quadrangle. The locations of the stations within the quadrangle are shown on the topographic map by small triangles. Fig. 1 (p. 10) shows the relations of the nine controlling points.

These stations are marked by stone posts, 6 by 6 or 8 by 8 inches in cross section, set about 3 feet in the ground. In the center of the top

[a] The author desires to acknowledge his indebtedness to Charles Butts and L. H. Woolsey, who did part of the geologic mapping of the quadrangle, and to M. R. Campbell, all of the United States Geological Survey, for advice and assistance; also to the gas companies for the use of their records, and to the superintendents of the several coal companies for valuable information.

of each post is cemented a bronze tablet marked "U. S. Geological Survey—Pennsylvania." For the convenience of engineers making surface surveys the following descriptions of these stations are given. Full details regarding the angles by which their positions have been determined can be found in Bulletin No. 181 of the United States Geological Survey, which can be obtained on application to the Director at Washington.

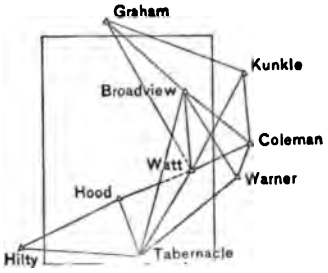


FIG. 1.—Diagram showing locations of triangulation stations on which the survey of the Elders Ridge quadrangle is based.

GRAHAM, ARMSTRONG COUNTY.

About 1 mile east of Blanket Hill post-office, on a bare ridge of cultivated land owned by the Graham heirs and rented by W. A. Blose. Latitude, 40° 46′ 17.28″. Longitude, 79° 24′ 50.74″.

KUNKLE, INDIANA COUNTY.

On land owned by Philip Kunkle, about 2 miles north of Creekside post-office, near western end of a high ridge having scattering trees on the eastern end. Latitude, 40° 42′ 28.78″. Longitude, 79° 12′ 14.09″.

BROADVIEW, INDIANA COUNTY.

About 2½ miles north of Shelocta and a few rods east of the Armstrong-Indiana county line; bare hill, with some timber on the southwest slope. The land is owned by John Russell. Latitude, 40° 41′ 16.95″. Longitude, 79° 17′ 28″.

COLEMAN, INDIANA COUNTY.

In White Township, about 2 miles northwest of Indiana, on high hilltop, on land owned by D. Coleman. Latitude, 40° 38′ 09.95″. Longitude, 79° 11′ 02.71″.

WARNER, INDIANA COUNTY.

About 3 miles southwest of Indiana, in White Township, on the highest part of a bare, roundtop hill, on land owned by Mr. Warner. Latitude, 40° 36′ 29.07″. Longitude, 79° 13′ 10.50″.

WATT, INDIANA COUNTY.

About 1 mile west of Tannery post-office and 1¾ miles southeast of Parkwood post-office, on the highest point of the western one of two hills of about the same height and 1 mile apart, on land owned by Thomas Watt. Latitude, 40° 36′ 02.99″. Longitude, 79° 16′ 45.32″.

HOOD, INDIANA COUNTY.

In Young Township, about 1 mile east of Elders Ridge post-office, on the highest point of a bare roundtop hill owned by Calvin Hood. Latitude, 40° 34′ 38.44″. Longitude, 79° 23′ 25.45″.

TABERNACLE, INDIANA COUNTY.

About 1½ miles southeast of Clarksburg post-office and about 6 miles by road northeast of Saltsburg, on the highest part of a bare, cultivated, roundtop hill owned by the heirs of S. W. Coleman. Latitude, 40° 30′ 54.57″. Longitude, 79° 21′ 49.71″.

HILTY, WESTMORELAND COUNTY.

In Bell Township, about 1½ miles north of Perrysville post-office, on the eastern *part of a bare knob*, and about 3 feet lower than the highest part of the hill, on land *owned by S. McCauley*. Latitude, 40° 31′ 28.40″. Longitude, 79° 31′ 59.01″.

BENCH MARKS.

Precise-level lines have been run over the Elders Ridge quadrangle, and elevations are based on and adjusted between bench marks established by spirit leveling. All bench marks are referred to an aluminum tablet in the foundation of the Seventh Avenue Hotel at Pittsburg marked "738 Pittsburg 1899," the elevation of which is accepted as 738.384 feet above mean sea level, and are stamped with the letters "Pittsburg" in addition to their figures of elevation. A list and description of the bench marks established in this quadrangle for the preservation of altitudes, with their precise elevations, as finally adjusted in 1903, follows. Where a whole number is given without decimals the altitude is not exact, being given only to the nearest foot.

Elevation of bench marks in Elders Ridge quadrangle.

SHELOCTA, PARKWOOD, AND KENT.

	Feet.
Shelocta, 2.75 miles east of; under clump of oak trees, rock, chiseled mark.	1,054.80
Shelocta, 1.25 miles east of; south side of road, near barn and nearly opposite house on north side of road, rock, chiseled mark	1,013.65
Shelocta, 0.25 mile east of; at intersection of roads, near covered bridge, rock, chiseled mark	994.45
Shelocta, covered bridge over Crooked Creek, at west end of; northeast wing wall of, coping stone, bronze tablet marked "992 Pittsburg"	991.414
Shelocta, 1.2 miles southwest of; south side of road, rock, chiseled mark.	1,046.42
Shelocta, 2.5 miles south of; opposite white house, under clump of locust trees, rock, chiseled mark	1,125.05
Shelocta, 2.75 miles south of; west side of road, opposite hickory tree, rock, chiseled mark	1,165.28
Parkwood, 1,000 feet north of; west side of road, rock, chiseled mark	1,331.42
Parkwood, 1.75 miles south of; bridge over Blacklegs Creek	1,082.00
Kent, 3 miles north of post-office; W. L. Neal's brick residence, on upper foundation stone, aluminum tablet, marked "1167 Pittsburg"	1,167.098
Kent, 2 miles north of post-office; Clark Neal's residence, in front of, on top of stepping block, chiseled mark	1,138.98
Kent, 0.25 mile north of post-office; by old barn, rock, chiseled mark	1,071.43
Kent, at intersection of roads at west end of; opposite blacksmith shop, rock, chiseled mark	1,055.49
Kent, 0.8 mile south of post-office; on east side of road, opposite sawmill, rock, chiseled mark	1,038.86
Kent, 2 miles south of post-office; James M. Jack's brick residence, on stone doorstep, bronze tablet, marked "1029 Pittsburg"	1,028.344
Kent, 3.5 miles south of post-office; bridge over Aultmans Run	982.00

SHELOCTA, ALONG HIGHWAY VIA ELDERTON, COCHRAN MILLS, AND ELDERS RIDGE TO JACKSONVILLE (KENT POST-OFFICE).

Shelocta, covered bridge over Crooked Creek; in wing wall of, bronze tablet, marked "992 Pittsburg"	991.414
Shelocta, 1.5 miles northwest of; large white house and barn, on gate in front of	1,004.00
Elderton, 2 miles east of; at road intersection, iron bridge over Plum Creek, floor of	985.00

	Feet.
Elderton, opposite hotel, on street corner; in west side of square stone hitching post, aluminum tablet, marked "1265 Pittsburg"	1,264.51
Elderton, 3 miles from; 0.5 mile east of Cherry Run, tree, nail in root of	1,124.55
Elderton, 3.5 miles from; bridge over Cherry Run, floor of	1,002.00
Cochran Mills, 3.1 miles northeast of; at fork of road, bridge, floor of	946.00
Cochran Mills, 1.5 miles northeast of; at road to east, bridge, floor of	917.00
Cochran Mills, iron bridge over Cherry Run; floor of	868.00
Cochran Mills, old covered wooden bridge over Crooked Creek; east abutment of, in northwest wing wall of, bronze tablet marked "871 Pittsburg"	870.429
Cochran Mills, 1 mile east of; near crest of hill, on rock, chisel mark projection	1,227.36
Cochran Mills, 2 miles east of; signboard tree, nail in root of	1,261.72
Girty, at road intersection, ground	1,003.00
Girty, 0.2 mile southwest of; bridge over Crooked Creek, on wing wall of, paint spot	945.97
Shady Plain, 0.5 mile north of; at road fork to west	1,393.00
Elders Ridge, 2 miles north of; 0.25 mile above schoolhouse, on left of road, rock	1,139.50
Olivet, at sign "West Lebanon 4 m.," road fork	1,079.00
Elders Ridge, Presbyterian Church, in southeast corner of, foundation stone, aluminum tablet marked "1226 Pittsburg"	1,225.639
Clarksburg, 1 mile west of; 300 feet west of coal pit, by side of road, log, nail in end of	1,137.89
Clarksburg, 1,000 feet west of Main street, large oak tree, nail in root of	925.08
Clarksburg, front of hotel, at corner of, on stone, chiseled square	917.85
Clarksburg, 0.75 mile east of; Blacklegs Creek, covered bridge over floor of	931.00
Clarksburg, about 2.5 miles east of; at left of road and above white house, white-oak tree, tack in root of	1,071.65
Clarksburg, about 3.5 miles east of; signboard tree, nail in root of	1,256.23
Jacksonville, Kent post-office, 1 mile west of; summit of road, ground	1,335.00
Jacksonville, Kent post-office, blacksmith shop near road intersection, on stone, chisel mark	1,055.49
AT EDRI.	
Edri, 0.1 mile west of station; railroad bridge, on west abutment of, on south end of bridge seat, copper bolt, Pennsylvania Railroad bench mark	834.55
Edri, 0.1 mile west of station; railroad bridge, in northwest corner of bridge seat, bronze tablet marked "834 Pittsburg"	833.732

TOPOGRAPHY.

SURFACE RELIEF.

The highest point in this quadrangle is Watt Hill, in Armstrong Township, Indiana County. Its top is 1,620 feet above sea level, or nearly 300 feet higher than the road corners at Parkwood. The point of least elevation is on Kiskiminitas River below Salina, where the level of the water is about 800 feet above tide. Crooked Creek has nearly the same elevation where it leaves the quadrangle a few miles to the north.

A. VIEW OF GENERAL TOPOGRAPHY.

Elderton in middle distance.

B. VIEW OF CONEMAUGH FORMATION TOPOGRAPHY, ROCKVILLE.

Throughout this quadrangle the surface is hilly. For this reason roads find better grades along the valleys than on the higher land, although some highways on the divides have easy grades for several miles. Pl. II, *A*, gives a broad view of the general topography, with Elderton in the middle distance, and Pl. II, *B*, shows in greater detail the character of topography developed on the Conemaugh formation. Rockville is in the foreground of the view. Because a large portion of the surface of the region is underlain by the rocks of one formation—and they vary but little from place to place—there is not much change in the character of the surface relief.

DRAINAGE.

The drainage system of this quadrangle is developed to the extent that streams penetrate all parts of the area. The main streams are still cutting rapidly and not building extensive flood plains. As is the case throughout much of western Pennsylvania, they are liable to floods, due to occasional heavy precipitation and to stripping of the former forest.

All of the drainage is tributary to Allegheny River. The streams are so small that none is navigable, even for rowboats, except on short stretches. The largest is Kiskiminitas River, which is formed by the junction of the Conemaugh and Loyalhanna at Saltsburg, about 3 miles south of the border of the quadrangle. The Kiskiminitas crosses the southwest corner, flowing due north for 2 miles, and then west at a right angle past Avonmore and Salina, about 5½ miles in all. It empties into the Allegheny near Freeport.

The main tributary of the Kiskiminitas in the region under discussion is Blacklegs Creek, which has its rise in the country about West Lebanon and Parkwood, and flows in a direct course to its mouth, 1¾ miles south of Edri, near the American Sheet Steel Company's plant. Big, Marshall, Hooper, Whisky, and Harper runs are the principal branches of Blacklegs Creek.

Crooked Creek is the second largest stream (Pl. III, *A*). It flows west across the northern half of the quadrangle in a course which its name describes. From Shelocta to Southbend, a village located almost in the center of the quadrangle, the stream flows through an open valley; but from Southbend to the western border it cuts a good-sized gorge, making steep rocky bluffs, in some places over 250 feet high.

The north and south branches of Plum Creek flow from the northeast and unite to form a stream which is increased by the waters of Dutch Run, and joins Crooked Creek about a mile above Idaho. Cherry Run collects its waters from Burrell, Kittanning, and Plum Creek townships and enters Crooked Creek at Cochran Mills between banks which rise abruptly to a height of 300 to 400 feet.

RELATION OF TOPOGRAPHY TO MAN'S ACTIVITIES.

Of the thirty or more hamlets in the Elders Ridge quadrangle, only a little more than half are on the banks of streams in the valleys; the others are on the uplands. The reason for the location of some of these settlements is apparent. Cochran Mills, for instance, is at the confluence of two streams, along which are main lines of travel, and is also the site of excellent water power. It is in a deep gorge, however, where there is room for only a few houses. The location of West Lebanon on the top of a hill 1,300 feet above sea level may have had its origin in the opening of a 7-foot bed of coal (Pittsburg) in the ravines which head around the hill. The principal occupation in this quadrangle is agriculture and grazing.

Roads for the most part are along the stream valleys, where the grade is easy. The longest stretches of stream-grade roads are along Blacklegs Creek, Crooked Creek above Girty, Plum Creek, and Cherry Run. Ridge roads are common and in some cases good. The road from West Lebanon to Spring Church is conspicuous on the topographic map for its directness and comparative levelness.

Crooked Creek carries a sufficient volume of water to furnish power for a number of mills. It falls 130 feet from Shelocta to Cochran Mills, a distance of nearly 18 miles as the stream flows; this furnishes enough head for water power at frequent intervals. Dams have been built at Cochran Mills, South Bend, and Idaho to run gristmills. Blacklegs Creek has been dammed near its mouth, where the grade is so low that the stream is ponded for some distance. Plum Creek and Cherry Run also are used for water power for small mills.

GEOLOGY.

STRUCTURE.

The rocks of the Elders Ridge quadrangle are bent into a number of nearly parallel wrinkles or folds which have a northeast-southwest trend. In describing these folds the upward-bending arch is called an anticline and the downward-bending trough is called a syncline. The axis of a fold is that line which at every point occupies the highest part of the anticline or the lowest part of the syncline, and from which the strata dip in an anticline or toward which they dip in a syncline.

METHOD OF REPRESENTING GEOLOGIC STRUCTURE.

There are in current use two methods of representing geologic structure. The first and most obvious method is by means of cross sections which show the various strata as they would appear if cut by vertical planes entirely across the quadrangle. This method is effective only where the dip of the rocks is perceptible to the eye. In the

A. CROOKED CREEK AT GIRTY.

B. MAHONING SANDSTONE NEAR SCHOOLHOUSE, JACKSONVILLE.

Elders Ridge quadrangle the rocks dip so gently that the anticlines and synclines would not be very apparent on such sections; besides, the sections illustrate the structure only along certain lines and do not give the shape of the arches and basins, and these are of the greatest importance in the commercial development of the field, as regards both the mining of coal and the exploitation for oil and gas.

The second method has been used in adjacent folios in the bituminous coal field of western Pennsylvania. It consists in the representation of the surface of some particular stratum which is known through its wide exposure in outcrop, its exploitation by mines, its relation to some other bed above it, or the records of wells drilled for oil and gas. The deformed surface of the key stratum is then represented by means of contour lines which show the form and size of the folds into which it has been thrown and its altitude above sea level at practically all points within the quadrangle.

In this quadrangle the Upper Freeport coal bed is a widely outcropping and well-known stratum and is used by drillers in some fields as a key rock in determining the position of the oil- and gas-bearing sands. The floor of this bed has been selected as the surface upon which to represent the geologic structure of the quadrangle.

Where the Upper Freeport coal shows in natural outcrop its altitude has been determined at many points. Where it occurs below the surface its existence and position are known through the records of the gas wells of the region. After its altitude has been determined at a great many places, points of equal altitude are connected by contour lines; as, for example, all points having an altitude of 900 feet above sea level are connected by a line, which then becomes the 900-foot contour line. Similarly, all points having an altitude of 950 feet are connected by the 950-foot contour line, and in like manner contour lines are drawn covering the entire territory at vertical distances of 50 feet. These lines are printed on the economic geology map, Pl. I, and they show, first, the horizontal contour of the troughs and arches; second, the relative and also the actual dip of the beds, and third, the approximate height of the Upper Freeport coal above sea level at any point.

The depth of the reference stratum below the surface at any point is obtained by subtracting its elevation, as shown by the structure contour lines, from the elevation of the surface at the same point. Suppose, for instance, the position of the Upper Freeport coal is desired at Parkwood. It will be seen by the map that the elevation of the surface at the road corners is 1,325 feet, and that the 800-foot structure contour line passes through the place. The Upper Freeport coal, therefore, is here about 1,325 minus 800 feet, or about 525 feet below the surface.

As a rule these structure contours are generalized, and are only approximately correct. They are liable to error from several condi-

tions. Being estimated on the assumption that over small areas the rocks maintain a uniform thickness, the position of a contour will be in error by the amount by which the actual thickness varies from the calculated thickness. It is well known that in some places the interval between two easily determined strata will vary by many feet in a short distance. Such cases make the determination of the position of the reference stratum difficult when it lies some hundreds of feet below the surface. In parts of the bituminous coal regions of Pennsylvania, however, records obtained in drilling for gas and oil give the changes in the interval, and thus control the determination of structure and the position of the reference stratum.

Another cause of error is that, being measured from the altitude of the observed outcrops, the position of the contour is uncertain to the degree that the altitude is approximate; while in many instances topographic altitudes are determined by spirit level, in most cases geologic observations are located by aneroid barometers. The aneroids are checked as frequently as possible against precise bench marks, and the instrumental error is probably slight, but it may be appreciable. Finally, the observations of structure at the surface can be extended to buried strata only in a general way. The details probably escape determination. These sources of error may combine or may compensate one another, but in any case it is believed that their sum is probably less than the amount of one contour interval; that is to say, the absolute altitude of the reference surface will not vary more than 50 feet from that indicated in any part of this quadrangle. Over much of the area the possible variation from the absolute altitude will not be more than 20 feet, and the relative altitudes for successive contours may be taken as a close approximation to the facts.

DETAILED GEOLOGIC STRUCTURE.

The general structural features of the Elders Ridge quadrangle have the same southwest-northeast strike that characterizes the whole Appalachian province. The folds in the rocks underlying this part of Indiana and Armstrong counties were recognized by Platt and described by him in Reports H4 and H5 of the Pennsylvania Second Geological Survey. The strongest features are three anticlines and two synclines. These axes are named from localities where they are strongly developed, or from places near which they pass. The first of these in this quadrangle, taking them in the order in which they occur from east to west, is the Jacksonville anticline, which passes near Lewisville and Jacksonville (Kent post-office). The next is the Elders Ridge syncline, which brings the Pittsburg coal down so that it lies in the hills under several square miles of this territory. The Roaring Run anticline parallels this syncline on the west for a short distance, but is broken up in the middle of the quadrangle. On the west of the Roaring

Run anticline is a basin which is not strongly developed on Crooked Creek, but becomes more pronounced to the north and may be known as the Apollo syncline. The lower end of the strong anticline which has been mapped across the Rural Valley quadrangle and is known there as the Greendale anticline crosses the northwest corner of this quadrangle.

These folds and basins in the rock structure are represented on the economic geology map by contour lines drawn on the floor of the Upper Freeport coal. These lines are drawn with a vertical interval of 50 feet and are printed in brown. This coal, which is used as a reference horizon, outcrops for a number of miles on Aultmans Run and in the region north of Jacksonville, on Plum Creek, Dutch Run, Roaring Run, and Crooked Creek in disconnected stretches as the rolls in the structure bring it above or carry it below the water level. The structure brings the coal so high above water level in the northwest quarter of the quadrangle that it outcrops for many miles along most of the tributaries of Crooked Creek.

Where the Upper Freeport coal is completely hidden beneath the surface, its position is calculated from higher beds in sight at the surface, with the assumption that intervals between members are fairly constant. In a few parts of the quadrangle the depth of the coal below the surface is known from deep-well records. The occurrence of the Pittsburg coal in the midst of the Elders Ridge syncline and midway between the outcrops of the Freeport coal on Aultmans and Roaring runs gives good control on the position of the latter bed beneath the surface in the southern half of the quadrangle. The interval between these two coal beds varies from 630 to 700 feet in this part of the State. The accuracy of this measurement is verified close to the axis of this basin by the record of a well drilled at water level near the mouth of Blacklegs Creek and close under the outcrop of the Pittsburg coal. The mouth of the well is about 320 feet below the Pittsburg coal, and the Upper Freeport coal was found at a depth of 324 feet, giving a thickness of 644 feet for the Conemaugh formation at this point. The determination of the position of the reference stratum throughout the entire quadrangle is believed to be accurate within a contour interval, and in those portions where the upper Freeport coal is exposed at the surface for long distances the variation from reality will probably be not more than 20 feet. Besides representing the depth of the reference stratum below the surface or its elevation above mean sea level, the contour lines show with some degree of accuracy the relation of the various slopes to each other and the approximate grades which may be expected if at any time mining operations are prosecuted upon this coal bed.

Jacksonville anticline.—The structural fold, which is a strong feature in the southeast corner of this quadrangle, reaches its greatest

elevation in the vicinity of the village of Jacksonville and takes its name from that place. To the south it crosses Conemaugh River about 2 miles east of Saltsburg and maintains a southwest course for some miles, gradually losing strength as it continues into Westmoreland County. To the north the crest of this anticline can be traced but a short distance beyond the boundary of this quadrangle; in fact, it is very inconspicuous on Curry Run and gives place to the McKee Run anticline, which is offset a short distance to the east. The Freeport coal on the crest of this anticline in the vicinity of Jacksonville is about 1,280 feet above sea level. From here it falls rapidly to the west, so that the Pittsburg coal, which is stratigraphically from 600 to 700 feet above it, is found at the same elevation above tide on the west side of the valley of Blacklegs Creek.

Elders Ridge syncline.—The Elders Ridge syncline was described and accurately located by the Second Geological Survey of Pennsylvania under the name Lisbon–West Lebanon syncline. This name, however, has been abandoned for the shorter one, which is taken from a small village in the center of this basin and located almost on the axis. The Elders Ridge syncline is traced across Indiana County from Plum Creek, dipping gradually to the south. Where the axis enters the Elders Ridge quadrangle, 3 miles east of Shelocta, the reference stratum is 900 feet above sea level. From here it falls gradually to a point between Elders Ridge and Big Run, where the Upper Freeport coal is not more than 400 feet above sea level. The axis rises from Big Run to the south fully 150 feet before it reaches the southern edge of the quadrangle. The Elders Ridge syncline crosses Kiskiminitas River near Edri, and pursues a comparatively direct course northeast through Elders Ridge near the academy, passes one-half mile west of West Lebanon, and in the valley of Gobblers Run turns sharply to the east, so that it lies fully a mile south of Shelocta. It is by reason of this syncline that the small area of Pittsburg coal is found on the hills. Westward from this axis the rocks rise more rapidly than to the east, and the Upper Freeport coal appears again on Roaring Run and Crooked Creek. From the description it will be seen that the Elders Ridge syncline is a canoe-shaped basin, and within the limits of this quadrangle is shallow at both ends and deepens toward the middle.

Dutch Run anticline.—North of the Elders Ridge syncline and east of the Roaring Run anticline in Indiana County there is a low structural fold which has enough strength to raise the Upper Freeport coal just above water level along the lower courses of Dutch Run and Plum Creek. The axis of this fold crosses the south branch of Plum Creek three-fourths of a mile east of the Armstrong-Indiana county line and crosses Dutch Run about the same distance west of Advance. It pursues a direct course to Plum Creek, paralleling Dutch Run for 3 miles, and crosses the former stream a mile above its mouth.

This axis was called the Roaring Run anticline in the Indiana folio under the misapprehension, on the part of the present writer, that the fold extended from Plum Creek to Crooked Creek and was a part of the axis seen on Roaring Run. The records of a number of wells obtained in this territory after the Indiana folio had been completed showed that the axis terminates 2 miles north of Idaho.

Although this fold is nearly parallel with the northeast portion of the Elders Ridge syncline and falls in line with that part of the Roaring Run anticline which lies south of Crooked Creek, it can not be considered as a part or a spur of the latter fold, for the reason that the axis of the Dutch Run anticline plunges toward the much higher flank of the Roaring Run anticline. This name, Dutch Run, is taken from the stream which the anticline mostly follows, and is used here for the first time.

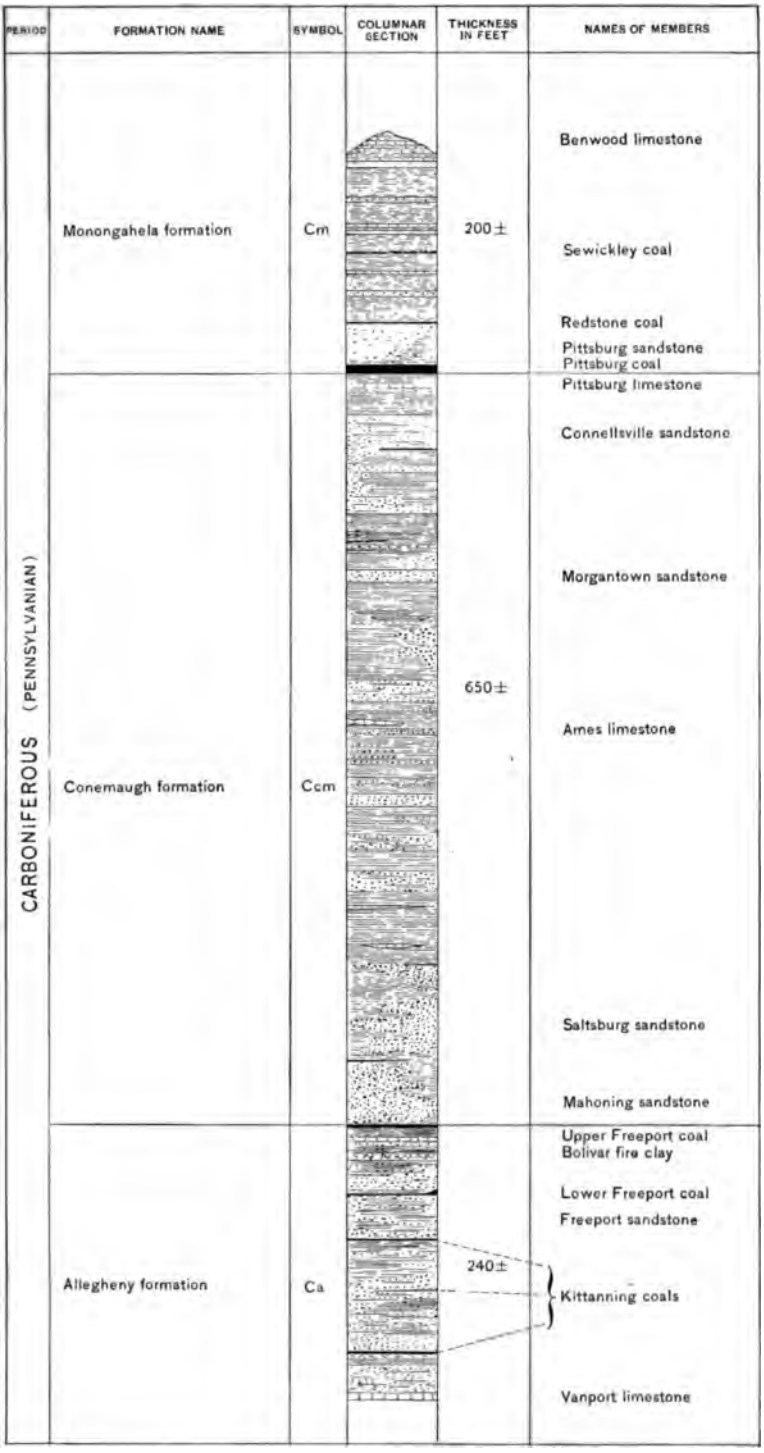
There is a synclinal basin north of Elderton and Gastown which is not considered to be a sufficiently important feature to receive a name. It assumes a very irregular shape in the Rural Valley quadrangle and is nameless there.

Roaring Run anticline.—In the Pennsylvania Second Geological Survey report on Armstrong County Mr. Platt describes an anticlinal axis which crosses Kiskiminitas River at the mouth of Roaring Run, and follows the course of that stream northeastward to Shady Plain and Elderton. He maintained that it was the Waynesburg (Bellevernon) anticline of Greene County, and described it as a continuation of the same, although he used the local term in his report. The present writer does not feel justified in correlating these axes before the intervening territory is mapped. This axis, as traced by the present writer, enters the quadrangle a little to the east of Roaring Run, but strikes into the stream toward its headwaters and passes directly through Shady Plain. On Crooked Creek in the vicinity of Girty there are two axes of about equal strength, and they seem to indicate that the Roaring Run anticline has a slight wrinkle on its crest for a short distance north of Shady Plain. The anticline decreases somewhat in height toward the north. The easternmost axis brings the Vanport limestone above water level about three-fourths of a mile east of Girty, and the westernmost crosses Crooked Creek near the neck of the "Loop," and also brings the limestone to daylight. Since the depth of the syncline between these two axes probably is less than 50 feet, and the Roaring Run anticline as a whole continues northward beyond the boundary of the quadrangle, it is not deemed necessary to apply a new name in Plum Creek Township, although Platt did so, calling the western axis the Fagley Run anticline. The numerous openings on the Upper Freeport coal in this vicinity give frequent elevations on the reference stratum, and also the dip of the rocks, and from this it has been determined that the western axis is the stronger in the highlands *between* Elderton and Cherry Run. At this point

the crest of the anticline rises again slightly, but falls off to the north and reaches its lowest point in the vicinity of the Say farm, 3 miles northwest of Elderton. The Roaring Run anticline continues a northeast course, and on the northern boundary of this quadrangle changes abruptly to a marked dome, the southern half of which is shown on Pl. I. This dome marks the extreme northern development of this anticline and terminates it 2 miles north of the boundary line of this quadrangle and about 2 miles east of Blanco in Cowanshannock Township. The position of the Upper Freeport coal in the northern part of the quadrangle, where the seam is below the surface, is determined by a number of deep-well records, and is probably accurate within a contour interval.

Apollo syncline.—This name is applied to a basin which is described by Mr. Platt as crossing the Kiskiminitas River under the village of Apollo, extending northeastward across Crooked Creek at Cochran Mills. Although the structural feature has not been traced southward to prove the connection with the basin which is seen on Kiskiminitas River, it is assumed that the correlation is correct and the name is here used. The basin, as it appears in this quadrangle, is seen on Crooked Creek and Cherry Run a short distance east of Cochran Mills, deepening to the northward, so that on the north branch of Cherry Run the Upper Freeport coal is carried a few feet below the surface for more than half a mile. The Apollo syncline passes east of Whitesburg and pursues a direct course toward Rural Valley. In Cowanshannock Township, however, this basin is very irregular, and its exact shape is determined with difficulty. A minor fold which raises the rocks probably 30 feet crosses Crooked Creek in the first bend below Cochran Mills, but apparently does not extend more than a short distance in either direction along the strike. This was described by Mr. Platt as the Apollo anticline.

Greendale anticline.—The anticline which enters this quadrangle north of Shay with a southward plunge, but appears to terminate before reaching Crooked Creek, is known as the Greendale anticline. It takes its name from the village of Greendale, which is situated near the point where the axis crosses Cowanshannock Creek. This axis as mapped in the Rural Valley quadrangle pursues a northerly course through Blanket Hill and Greendale, where its shape is irregular, particularly along the crest. The axis after crossing Cowanshannock Creek swings eastward to Belknap. In the Elders Ridge quadrangle it has the effect of keeping the Upper Freeport coal above water level for a number of miles on the north branch of Cherry Run, in Kittanning Township, and also on Elbow Run and other tributaries of Crooked Creek. This anticline is described by the earlier survey as continuing southward, but, so far as has yet been determined, it does not continue much beyond Crooked Creek.



GEOLOGIC SECTION IN ELDERS RIDGE QUADRANGLE.

STRATIGRAPHY.

CARBONIFEROUS SYSTEM.

All of the rocks seen at the surface in this quadrangle belong to the Pennsylvanian series of the Carboniferous system. Three formations are present—the Allegheny, Conemaugh, and Monongahela. These are, respectively, the Lower Productive, Lower Barren, and Upper Productive measures. The Allegheny formation is exposed along Roaring Run, Crooked Creek, Plum Creek, Dutch Run, and Aultmans Run—a small portion of the whole surface. The Monongahela formation underlies a belt of country about 9 miles long and 3 miles wide between Kiskiminitas River and West Lebanon. The rocks underlying the remainder and by far the largest portion of the surface belong to the Conemaugh formation (Pl. I). More than 1,100 feet of stratified rocks are exposed at the surface in this quadrangle. They are divided among the formations as follows: Allegheny, 240; Conemaugh, 650; Monongahela, 216. A graphic representation of the section exposed in this quadrangle is given on Pl. IV.

ALLEGHENY FORMATION.

The Allegheny formation extends from the base of the Brookville coal to the top of the Upper Freeport coal and is 300 feet thick.

The whole formation does not reach the surface in this quadrangle, the lowest strata seen being the Vanport limestone. The interval from the top of the formation, which is the Upper Freeport coal bed, to the bottom of this limestone is 250 feet. It can be measured near Girty on Crooked Creek, where the limestone outcrops at water level and the coal is opened in the hills north of the creek. It is impossible to measure a detailed section of this formation at any one place. Measurements of different local exposures accurately joined together in their regular order of superposition give the section which follows. It represents the average condition of the upper part of the Allegheny formation as exposed in this quadrangle.

Partial section of Allegheny formation.

	Feet.
Upper Freeport coal	4
Shale	8
Limestone	3
Sandstone	4
Shale	5
Fire clay	8
Sandstone and shale	30
Lower Freeport coal	2
Shale and sandstone	18
Freeport sandstone	25
Upper Kittanning coal	1

	Feet.
Sandstone and shale	70
Sandstone	25
Lower Kittanning coal	3
Fire clay	8
Shale, iron nodules, and sandstone	22
Vanport limestone	10
Total	246

Vanport limestone.—A widely known limestone occurring in the lower portion of the Allegheny formation is the lowest member which outcrops in this quadrangle. It is commonly called the "Ferriferous" limestone, but the name "Vanport limestone" has been recently revived for it and will be used here. Vanport is a village on Ohio River, 3 miles below Beaver, where the limestone is well exposed. At water level on Crooked Creek, east of Girty, and around the "Loop," 2 miles west of the hamlet, the Vanport limestone is exposed. It shows 8 to 10 feet of solid limestone, dark bluish gray on the fresh-broken surface, but revealing a large number of white fossils (mostly crinoid stems) on the weathered surface. It is compact, rather coarse, and very brittle. The richly fossiliferous weathered surface is a distinguishing feature. The exposed edge often has a pitted appearance, due to irregular weathering along bedding planes. Above the limestone is 22 feet of sandstones and shales, the upper layers containing iron-ore nodules. This horizon is overlain by 8 feet of fire clay, often of poor quality, which underlies the Lower Kittanning coal bed.

Lower Kittanning coal.—This coal lies at varying intervals above the Vanport limestone. In different parts of western Pennsylvania the interval may vary from 5 to 45 feet, but the occurrence of the coal is very constant. The outcrop line of the coal in this quadrangle would vary but little from that of the Vanport limestone as shown on the map, because the coal is only 30 feet above it. The coal is at the surface for only short distances on Crooked Creek. The thickness of the bed in Armstrong County is about 3 feet 6 inches, but it varies in different localities. At the "Loop" it is overlain by 25 feet of sandstone. Above this sandstone, whose massive character is not persistent, is an interval of 70 feet or more, in which occur sandstone and shale. The presence of the Middle Kittanning coal has not been recognized in this region. Its place is in the midst of these shales and about 60 feet above the Lower Kittanning coal. Some of the sandstone a few feet above the Lower Kittanning coal is so fine grained, even, and thin bedded that it has been quarried for paving and tombstones.

Upper Kittanning coal.—This bed caps the series of soft rocks and is usually present at its proper horizon. It has a thickness of scarcely more than a foot, and is therefore of little value. A few inches or feet of shales separate it from the Freeport sandstone, which in this region has a thickness of 25 feet. It is often massive, coarse grained,

and mottled with iron stains, but in places becomes shaly. A typical section of this sandstone in its massive condition and of the underlying Upper Kittanning coal with the Johnstown limestone is seen at Cochran Mills, in the bluff opposite the mill, and also at the road corner, three-quarters of a mile southeast of Girty.

A series of soft rocks composed of clay shales and sandstones overlies the Freeport sandstone. The members are thin and interstratified, so that the outcrop weathers rapidly and conceals itself with débris. This series is about 18 feet thick.

Lower Freeport coal.—The outcrop of this coal is usually hidden by wash from above and the extent of the coal bed is concealed. It may be persistent, but this is not known for a fact. Its blossom and a few exposures seen in this quadrangle indicate that the bed is from 15 inches to 2 feet thick. There is, however, an unusual development of the seam on Neal and Reeds runs, north of Jacksonville, where the Lower Freeport reaches a thickness of 5 feet, while the Upper Freeport, 60 feet above, retains its customary dimension. This occurrence will be described later. A layer of black slate, usually about a foot thick, forms the roof of the lower coal bed. The interval between it and the Upper Freeport coal is from 30 to 60 feet, and is occupied largely by shales with thin layers of sandstone. In the valley of Crooked Creek, below South Bend, the Butler sandstone, which lies between the Upper and Lower Freeport coals, is massive and conspicuous. It is coarse grained, gray, and forms the upper part of the bold cliff at Cochran Mills. A fire clay of varying thickness and quality overlies the shales and forms the floor of the coal seam which marks the top of the Allegheny formation. The fire clay which lies immediately below the coal is impure and calcareous, but that found 12 or more feet below the coal is often good, and is worked at Salina by the Kier Fire Brick Company.

Upper Freeport coal.—A coal bed of workable thickness which outcrops in many places in this quadrangle is known as the Upper Freeport. Its outcrop in the hills and valleys on three sides of the territory is long and irregular, as it is brought to light in the many side valleys which branch off from the main streams. This coal bed persists throughout a large area in western Pennsylvania and maintains a fairly constant thickness of 4 feet. Along Roaring Run and its branches the coal has been opened on almost every farm. A section measured in the Hilty mine a mile south of Equitable and on the axis of the anticline is as follows:

Section on Roaring Run.

	Ft.	In.
Coal	3	7
Shale	0	1
Coal	0	11
Total	4	7

This section is an average one of the region and shows the thin parting shale which is characteristic of the seam on Roaring Run. This seam is thicker in the western part of the quadrangle and at the openings on the Grey farm near Long Run than it is elsewhere within the boundaries of the district. Sections measuring little more than 3 feet are common, and where a thickness of 5 feet or more is found the seam is much broken by partings, or the lower benches are so small and separated from the upper bench by so much shale, that it does not pay to remove the burden in order to get the coal.

In the valley of Crooked Creek the Upper Freeport coal is found always in the hills from South Bend westward to the Allegheny River. It is commonly about 3½ feet thick, contains one or more shale partings, and is never free from iron pyrites.

CONEMAUGH FORMATION.

The Conemaugh formation includes the rocks from the roof of the Upper Freeport coal to the floor of the Pittsburg coal. The Mahoning, Saltsburg, Morgantown, and Connellsville sandstones are the prominent members of the formation, and their presence is often shown by the number of large blocks of sandstone scattered over the surface. All of these sandstones when well developed and massive have much the same appearance. They weather grayish-white, are sometimes iron stained, vary from coarse to fine grain, and are best recognized by their position in the geologic section. The formation is composed largely of shales. These are variegated and show green, gray, and red tints. There are several insignificant beds of limestone, none of which are valuable as key rocks in this quadrangle.

The frequent changes and modifications which these strata undergo are shown by exposures, natural and artificial, found on the highways and along stream courses, the thickness and character of the members often changing so completely in a short distance that sections only a few hundred feet apart may have little resemblance.

The entire Conemaugh formation is present only in the region of the Pittsburg coal, between Long Run and Blacklegs Creek. It forms the upland of the quadrangle, except in the above-mentioned belt, where the Monongahela formation is present.

The thickness of the formation is over 600 feet, and yet there is nothing in it of particular economic interest except the massive sandstones. A generalized section is as follows:

Generalized section of Conemaugh formation.

	Feet.
Shale	8
Pittsburg limestone	5
Fire clay	3
Shale	24
Connellsville sandstone	30

Generalized section of Conemaugh formation—Continued.

	Feet.
Sandstone, shale, and thin limestones	100
Morgantown sandstone	20
Shale, sandstone, and thin limestones	320
Saltsburg sandstone	45
Sandy shale	40
Mahoning sandstone	50
Shale	5
Total	650

Mahoning sandstone.—The roof of the Upper Freeport coal, which is the bottom of the Conemaugh formation, is usually a bed of shale varying in thickness from nothing to 10 feet. Over this is a heavy bed of massive sandstone, which rests on the shale; or in places the shale is cut out and the sandstone rests directly on the coal. This sandstone, commonly called the Mahoning, has a thickness of 50 feet or more, and often stands out in bluffs, or strews the surface with large blocks. The blocks are particularly conspicuous about Jacksonville (Pl. III, *B*, p. 14), and the massive sandstone is well exposed on Roaring Run and about Salina. In the northern part of the quadrangle, beyond Crooked Creek, this member loses something of its massive character and is less conspicuous for that reason, although it is seen frequently between Elderton and Cherry Run. It is recognized largely by its thickness and position immediately above the Upper Freeport coal, for its grayish-white color, its hardness, and grain are equally characteristic of other sandstones in the formation. In the northeast corner of the quadrangle the Mahoning sandstone horizon is occupied by shale.

Saltsburg sandstone.—The succeeding 40 feet comprise a mass of sandy shales, which in the Conemaugh region are overlain by a heavy sandstone. This rock is traceable along the southern line of the quadrangle by an abundance of sandstone débris and some outcrops. It is known as the Saltsburg sandstone, and can be seen to the best advantage in the bluff opposite the village of that name. The top of this member is generally about 150 feet above the Upper Freeport coal. In the hills on both sides of Kiskiminitas River at Salina this member has a massive character, and outcrops conspicuously in the roads and ravines. It is also well exposed at the road forks known as "Flat Rocks," on the ridge west of Long Run. Here it shows a grayish-white surface, but on a fresh-broken face often is iron stained. It has a medium coarse grain, in places finely conglomeratic with quartz pebbles a half inch in diameter. The Saltsburg sandstone is thin bedded and shaly in the northern part of the quadrangle and could not be traced continuously. In Plum Creek Valley the Mahoning sandstone seems to be but a few feet thick, and the Saltsburg horizon is occupied by shales.

Two thin coal seams are found occasionally at intervals of about 50 and 100 feet above the base of this formation. The lower one has been seen 18 inches thick, but the upper one is usually 3 to 5 inches.

From the top of the Saltsburg sandstone for 320 feet is a monotonous series of thin sandstones, shaly sandstones, and shales which present no conspicuous or traceable members. The interval contains several very thin intermittent layers of limestone. One of these, which is probably not far above the top of the Saltsburg, is 8 inches thick, black, and contains many fossils. The black shale immediately underlying the limestone contains even more animal remains, the most numerous being an elongated spiral gasteropod of the genus *Bulimorpha*. Bellerophons also are numerous. There is a good exposure of this black fossiliferous limestone in the creek bank beside the road three-quarters of a mile west of Shelocta. A green limestone about 1 foot thick is sometimes found near the middle of the formation, about 340 feet above the Upper Freeport coal. It carries abundant brachiopods and crinoid stems, and can be seen on Walford Run 1¼ miles southwest from Avonmore. According to I. C. White this would be the Ames limestone, which he describes[a] as occurring throughout Pennsylvania about 275 to 300 feet below the Pittsburg coal and the same distance above the Upper Freeport coal, increasing in places to 350 feet. The position of this limestone also agrees with White's section[b] in Beaver County, south of Ohio River. In his section of the Lower Barren measures in Armstrong County[c] Platt places the green Fossiliferous limestone, which is another name for the Ames limestone, 212 feet below the Pittsburg coal. Some thin limestone was noted at this horizon by the writer, but not recognized as described. Furthermore, Platt's section is 100 feet shorter than the thickness of the formation determined in this quadrangle. Whether either of these limestones can be correlated with the type is an open question.

Morgantown sandstone.—It is difficult to recognize the Morgantown sandstone in this quadrangle because of its thin-bedded shaly character. Its position seems to be a little less than 200 feet below the Pittsburg coal. The bed was named from the city of Morgantown, W. Va., where it is well exposed and extensively quarried. The Morgantown sandstone is often underlain by red shales and is overlain by 50 feet of variegated shales which sometimes contain three thin beds of limestone. The horizon of these limestones is approximately 150 feet below the Pittsburg coal, and this part of the section is well exposed and can be measured in the west bluff of Kiskiminitas River half way between Edri and the mouth of Blacklegs Creek.

Connellsville sandstone.—There is generally present in this quadrangle, at a distance of 40 feet below the Pittsburg coal, a coarse sand-

[a] Bull. U. S. Geol. Survey No. 65.
[b] Second Geol Survey of Pennsylvania, Rept. K, p. 334.
[c] Platt, W. G., Second Geol. Survey of Pennsylvania, Rept. H5, p. 6.

stone which has received its name from the city of Connellsville, where it outcrops conspicuously. The bed is usually 30 feet thick. It is massive or slightly shaly, and underlain by red shales and shaly sandstone. The Connellsville in its massive condition is a grayish quartzose sandstone, sometimes iron stained, and in no way different from other sandstones in the formation. It is recognized solely by its geologic position. It lies so near the Pittsburg coal that its importance as a key rock is overshadowed by the coal, which is better known in its outcrop and in its underground extension than any other member of the series.

Pittsburg limestone.—A limestone, which is separated from the Pittsburg coal by a few feet of shale, outcrops at a number of places in the southern half of this quadrangle. It can be seen on several roads within a mile or two of Olivet. The limestone is about 5 feet thick and moderately pure. It is generally compact, moderately heavy-bedded, and brittle. The weathered surface is light colored, but on a fresh fracture it shows bluish gray seamed with bluish black.

MONONGAHELA FORMATION.

The Monongahela formation consists for the most part of shale, sandstone, and limestone. The Pittsburg coal, the most important seam in the region, is found at the base and other less important beds above. The usual thickness of the Monongahela formation is about 375 feet, extending from the Pittsburg coal at the base to the Waynesburg coal at the top. About 216 feet of the formation is present in this quadrangle, the upper portion having been removed by the general degradation of the land surface. The average thickness of the rocks above the Pittsburg coal is about 100 feet in this region; the 200-foot intervals occur but rarely. The area to which the Monongahela formation is confined in this quadrangle is about 12 miles long by 3 miles wide. Its limits are defined on the north by Gobblers Run, on the east by Blacklegs Creek, on the south by the quadrangle boundary, and on the west by Long Run (Pl. I).

The highest rocks in this quadrangle, in a geologic sense, are found in the vicinity of Elders Ridge and West Lebanon, where the Benwood limestone caps several hills in the basin of the Elders Ridge syncline.

A geologic section for this region must be generalized and the result of compilation of measurements from several localities. The following gives an idea of the sequence of rocks exposed in the basin, but does not indicate the frequent variations which occur:

Partial section of Monongahela formation.

	Feet.
Benwood limestone	25
Sandstone	7
Sandy shale, sandstone, and limestone	76
Sewickley coal	2

	Feet.
Shale	12
Limestone	6
Shale	15
Sandstone	5
Shale	25
Redstone coal	1
Sandstone	30
Shale	5
Pittsburg coal	7
Total	216

Pittsburg coal.—The basal member of the Monongahela formation is the Pittsburg coal. The bed has hundreds of miles of outcrop in western Pennsylvania, and is well and favorably known for its coking and steaming qualities. It is usually from 7 to 10 feet thick, with thin shale partings, and can be traced easily by the numerous springs, coal blooms, and openings on the outcrop and by the broad bench on the slopes over which it runs.

The Pittsburg seam reaches its most northern development in this quadrangle (fig. 3, p. 43). It exists in three irregular areas of nearly equal size which lie along the Armstrong-Indiana county line. The boundaries of the coal area are the same as those of the Monongahela formation. It does not extend east of Blacklegs Creek or west of Long Run, and the most northern occurrence is in the hills just north of West Lebanon. On the south side of the river, in Westmoreland County, the coal has a more extensive development, only a small area of which is included in this quadrangle. The deep ravines, which cut entirely through the coal seam and divide the belt into separate areas, together with notches made on all sides by small streams, furnish long and irregular lines of outcrop and ready access to the coal in the basin. The bed dips gently from all directions toward the lowest point on the synclinal axis, which is between Elders Ridge and Big Run.

The coal is about 300 feet above the river at Hicksville and 200 feet above Clarksburg on Blacklegs Creek. It lies beneath the villages of Elders Ridge and West Lebanon. The dip of the bed and its elevation above the river are favorable to mining and transportation. The shales forming the roof of the Pittsburg coal vary in thickness from 1 to 8 feet and are overlain by sandstone.

Pittsburg sandstone.—The sandstone which begins a few feet above the Pittsburg coal is known by the same name. It is 30 to 40 feet thick near the river and forms cliffs in the hilltops overlooking Avonmore. Its character is generally massive and the bowlders that break off from the outcrop are large. Toward the northeast this massiveness becomes less pronounced and the thickness decreases. South of Olivet it is current bedded, making it suitable for flagging. The sand-

stone, which is directly above the Pittsburg coal near West Lebanon, is only 25 feet thick and so thin bedded that it weathers off into thin, soft fragments. This extreme variation from massive and compact to loose and shaly carries with it a change from quartzose to clayey and from gray to dark colored.

Redstone coal.—There is a small seam of coal above the Pittsburg sandstone, separated from it by a bed of clay, but it is not thick enough to be worked. In fact the bed scarcely more than shows itself in the most favorable exposures. It is reported as being present and nearly 3 feet thick in the vicinity of Elders Ridge. This thickness probably is made up largely of shale partings. In the southern part of the field near Kiskiminitas River it seems to be absent.

Above the Redstone coal for 45 feet the rocks are shale with some thin sandstones and arenaceous shales so soft that they weather deeply. A limestone which averages 6 feet thick occurs at the top of this interval. It is fossiliferous, fairly pure, sometimes has a brownish cast, and is easily calcined. It is exposed in the bluff on the river and has been opened in a ravine at Olivet. So far as known it has not been explored elsewhere and its exposures are few. The name commonly given to this member of the formation is Sewickley limestone.

Sewickley coal.—The extent of this coal throughout the basin is much less than that of the Pittsburg, for it is 100 feet higher in the hills. It has a thickness of 2 to 5 feet and is found frequently with strong bloom, showing a persistence in its occurrence. So long as the Pittsburg coal bed is near by, this coal seam can not be worked with profit, and it is not mined at present within the boundaries of the quadrangle. This coal shows at the extreme hilltops in the northern bluffs below Hicksville and is seen frequently in the roadside ditches near Elders Ridge. Above the Sewickley coal is an interval of about 80 feet which consists mainly of argillaceous shale. These rocks weather easily and produce good soil.

Benwood limestone.—This bed is found only on Elders Ridge, and only the lower part of the member is here present. It consists of several layers of limestone separated by variable intervals of shales, in all about 25 feet. The limestone is grayish in color, smooth and compact, and nonfossiliferous. It has been burned for making fertilizer and found excellent for that use, as it makes a strong lime and is easy of access. No stripping is required in order to quarry it, because all the limestone lies in the very crown of the highest knolls in the middle of the basin. Where the bed is present abundant fragments of gray limestone are usually spread over the ground.

QUATERNARY SYSTEM.

Carmichaels clay.—Deposits of gravel, sand, and clay are found at a number of places high above the present flood plains of Kiskiminitas

River and Crooked Creek within the boundaries of this quadrangle. The presence of water-laid deposits, rounded pebbles, and stratified sands at an elevation of 100 feet or more above the streams is a feature of the geology in many valleys in this part of the State. These sands and clays were laid down as alluvial deposits on valley floors which have subsequently been dissected.

The occurrence of these terrace deposits and their elevation above the present streams is shown on the economic geology map (Pl. I). In the vicinity of Shelocta the terrace deposits are only a few feet above the reach of the highest floods on Crooked Creek and the slopes away from the stream are so gentle that it is difficult to determine where the recent alluvium stops and the terrace deposits begin. In fact it is quite probable that the gravels and sands of the older river stages have washed down upon and merge with the present flood-plain deposits. On the same stream below Girty well-rounded pebbles and river silts have been found in a number of places at an elevation of 100 feet or more above the creek. Back of the village of Avonmore on Kiskiminitas River there are well-developed terrace deposits at an elevation of 80 feet above the river, and also on the broad upland above the village 100 feet higher than the first bench, at an elevation of about 1,000 feet above tide. The character of the deposits as shown in street cuttings in the southeastern part of the village and in tilled land on the upper flat is interstratified gravel, sand, and clay. These were laid down during the periods of no crustal movement in which the valley floors were broadened.

Alluvium.—The activity with which the streams are deepening their channels interferes with the development of extensive flood plains. Where these recent river deposits have accumulated to some extent they are represented on the geologic map. Alluvium consists of sand, clay, and silt, the disintegrated rock particles which have been washed down from the hillsides and deposited in their present position in time of high water. Kiskiminitas River, where it crosses the southwest corner of this quadrangle, has a flood plain above Edri, but below that point is confined within steep banks on one or both sides. Opposite Avonmore and below Salina the side walls are precipitous and rocky and no alluvium is deposited.

Blacklegs Creek has built a narrow flood plain along several miles of its course. It is nowhere more than a few hundred yards wide, and is only a minor feature of the geology. Cherry Run has no alluvium broad enough to be represented on the map, and Aultmans Run shows only a small amount.

Crooked Creek is in a narrow gorge below Girty, but has some wide flood plains along its course east of that village and on its tributaries. Plum Creek, in particular, has a broad, flat, valley bottom, and is conspicuous on the maps for its wide floor. Dutch Run, which empties

into Plum Creek, also has a flood plain broad enough to be represented on the map along several miles of its course.

These alluvial deposits often afford good soil, and are extensively cultivated in those places where danger from floods is not too great. The fine character of the material and levelness of the surface make them easy to till, and where this is not done the flood plains make good pastures.

MINERAL RESOURCES.

COAL.

Coal is the most important of the mineral resources of the Elders Ridge quadrangle. Two beds of workable thickness are extensively exposed. These are the Upper Freeport and the Pittsburg. A third bed, the Lower Freeport, which is usually thin, has a local importance in some places where it thickens considerably. Several other beds too thin to be of economic importance are present. These coals are in the Allegheny and Monongahela formations, and lie between the Vanport and Benwood limestones. Although eight or nine seams occur in this interval, it must not be assumed that they are everywhere present or are always of the same thickness. The generalized sections so often published are meant to show only their relative positions. It should be understood that these beds vary in position with relation to other beds and that their thicknesses are not constant. The description will begin with the lowest coal exposed in the area and end with the highest. No mention will be made of the Gallitzin and Redstone coals, which are mere streaks where seen and undoubtedly are small throughout the quadrangle.

It may be well here to define certain terms in common use. An opening is a small excavation which reveals the coal in place and the thickness of the bed. A coal bank is a small mine in which a few men, from 1 to 10, are employed, and in which the coal is mined and brought out to the scaffold without the use of machinery. A coal mine employs enough men to require a mine boss, probably uses machines for undercutting the coal, and hauls by means other than hand. Coalpit is a term applied without discrimination to openings, banks, and mines.

LOWER KITTANNING COAL.

The horizon of the Lower Kittanning coal is seen above water level on Crooked Creek for some distance between South Bend and Cochran Mills. It is in no place more than 50 or 60 feet above the stream and its outcrop line coincides closely with that of the Vanport limestone shown on Pl. I, because both are in the deep gorge of the creek. This is the only place where this coal is seen in the Elders Ridge

quadrangle. It is not being worked anywhere on the creek at present and never has been mined to more than a very small extent. It had been opened previous to the Second Geological Survey of Pennsylvania, and the reports of the Survey state that the coal averaged about 3 feet where seen at the old salt works below the "Loop" (fig. 2, *A*). A section measured by the writer in a small ravine two-thirds of a mile below the "Loop" is as follows:

Section on Crooked Creek below Girty.

	Ft.	in.
Sandstone	10	0
Lower Kittanning coal	2	7
Clay	6	0
Sandy shale	30	0
Vanport limestone	8	0
Creek level		

This coal was also mined at one time near the bridge at Girty. It is highly pyritous, and is so much broken by parting slates that the seam is nearly worthless for practical purposes. In a detailed section measured by the Second Geological Survey of Pennsylvania the bed is subdivided (fig. 2, *B*):

Section of Lower Kittanning coal at Girty.

	Ft.	in.
Slaty clay		
Coal	0	6½
Slate	0	1
Coal	1	6
Slate	0	½
Coal	0	3
Total	2	5

MIDDLE KITTANNING COAL.

If this coal bed is present in the Elders Ridge quadrangle it can outcrop only in the region described for the Upper Kittanning coal. Its blossom was nowhere recognized, and it is presumed that the bed is extremely thin. The report of the Second Survey gives it a thickness of 6 inches.

UPPER KITTANNING COAL.

This coal bed also is seen only in the valley of Crooked Creek below South Bend. It is nowhere of practical importance, although it was at one time developed to a small extent at the mouth of Cherry Run for household use. The first occurrence of this coal noted in going downstream is a blossom in the highway at the mouth of Sugar Run. The bed appears to be about a foot thick at this point and is underlain by Johnstown cement limestone. The coal has been stripped farther up Sugar Run from the bed of the stream, and is reported to be 2 feet *thick.* At Cochran Mills the Upper Kittanning coal has been opened

at the bluff on Crooked Creek and at the mouth of Cherry Run opposite Mr. Kinnard's house. There are also several old openings on Cherry Run along which the coal outcrops for some distance. The bed is about 2 feet thick (fig. 2, *C*) in this locality, and was mined

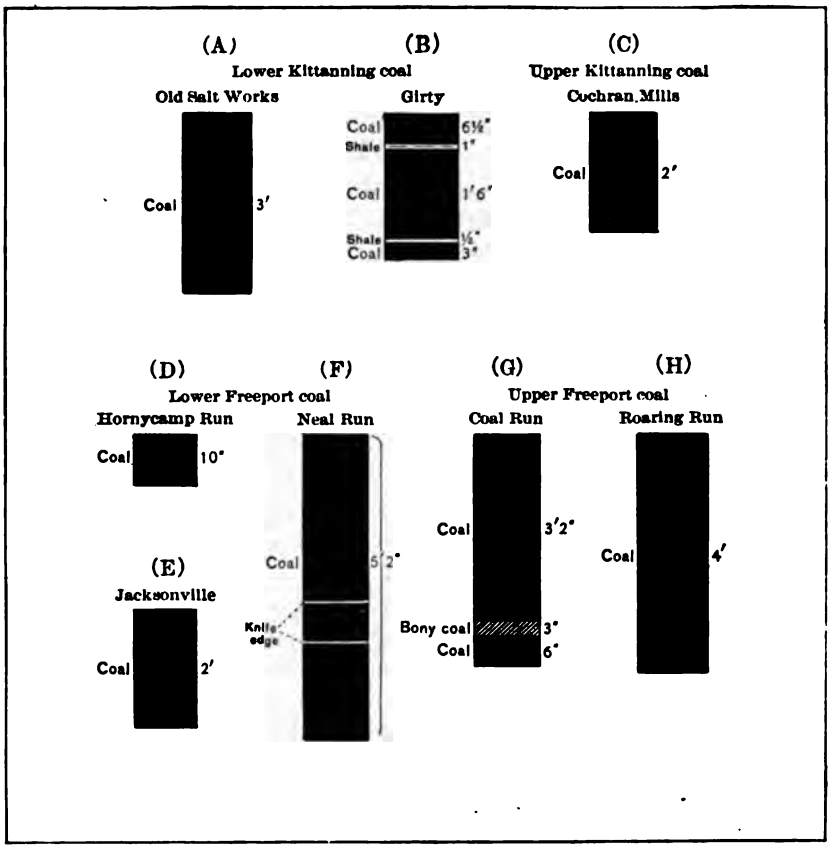


FIG. 2.—Sections of Kittanning and Freeport coals.

because its location was more convenient than that of the Upper Freeport coal, which is in the top of the bluff. A section measured at Cochran Mills is as follows:

Section at Cochran Mills.

	Feet.
Freeport sandstone	45
Sandy shales	30
Upper Kittanning coal	2
Fire clay (impure)	2
Johnstown cement limestone	3
Clay and shales	5
Slates, dark	20
Creek level	
Total	107

Farther down Crooked Creek the thickness of this seam diminishes to a mere streak, and its blossom is seen very infrequently. It is nowhere of practical importance in this region.

LOWER FREEPORT COAL.

Whether this seam is present throughout the Elders Ridge quadrangle is questionable. The horizon is well exposed in the ravine at Cochran Mills, but no trace of the coal was seen there, and in fact it was not recognized more than two or three times in the valley of Crooked Creek. A small coal blossom was seen on the township road 1 mile east of Girty at the end of Mr. Barr's lane, and in a small ravine south of the "Loop" on Crooked Creek another exposure was seen in which the coal is reported to be about 18 inches thick. On Hornycamp Run, which is 1 mile south of Elbow Run, a 10-inch coal, believed to be the Lower Freeport, shows at the roadside south of the schoolhouse (fig. 2, *D*). It is commonly reported at Rockville that there is a coal bed a few feet below the surface of the run, and two or three wells which have been drilled at water level have found coal at a depth of 15 or 20 feet. If this is the case, it is probably the Lower Freeport seam, and although the drillers say that it is several feet thick their statement has not been proved. It is probable that the seam will not measure more than 2 feet thick wherever it is found in this part of the quadrangle.

In the vicinity of Jacksonville, Conemaugh Township, the Jacksonville anticline raises the Allegheny formation high above water level, so that the horizon of the Lower Freeport coal is exposed for a number of miles. The coal is not more than 20 inches thick on Reeds Run, and it is probably less than 2 feet thick at the head of Neal Run. The bed has been opened on the east hillside three-fourths of a mile north of Jacksonville and found to be only 2 feet thick (fig. 2, *E*). This is probably the normal occurrence for this part of the county. Near the mouth of Neal Run, however, the Lower Freeport has an unusual development. It is mined near the schoolhouse 2 miles north of Jacksonville by Mr. Clark Neal and Mr. William H. Martin. In both these banks, which are nearly opposite each other on the same run, the Lower Freeport coal measures 5 feet 2 inches (fig. 2, *F*). The bed is very even and does not carry a large per cent of sulphur, but is considerably intermixed with thin bands of earthy material which in places gives it a large percentage of ash. It is the presence of this impurity that gives it its great firmness, causing it to come from the mine in large blocks. The coal has a dull luster generally, but shows numerous bright pitchy bands. The lower bench, which is 20 inches thick, is harder than the rest. It is overlain by 8 inches of a softer coal which is excellent for blacksmithing purposes. Mr. Neal produces from 20,000 to 30,000 bushels annually, and Mr. Martin from

10,000 to 15,000 annually. The coal has been mined on this run continuously for nearly sixty years. In the first hollow south of Neal Run the same bed has been mined on the Marshall farm close to the axis of the Jacksonville anticline, the seam measuring 4 feet 6 inches thick.

It is believed by some people in the vicinity that the Lower Freeport seam maintains a thickness of from 4 to 5 feet throughout a considerable area in this part of Indiana County, but this is readily disproved by an examination of the outcrops in the immediate vicinity of the coal banks above mentioned. It is possible that the bed attains the same thickness at other points where it is hidden beneath the surface, but it is quite certain that the development on Neal Run is very local, and will extend less than a mile in any direction.

A coal reported to be 5 feet thick in the Stahl well (261) is at the proper horizon for the Lower Freeport. It is a churn-drill measurement, however, and therefore unreliable. The bed is not known on Conemaugh River a few miles south of this well.

An average specimen of this coal, analyzed by Mr. A. S. McCreath for the Second Geological Survey of Pennsylvania (Rept. IIHHH, p. 251), is as follows:

Analysis of Lower Freeport coal on Neal Run.

	Per cent.
Fixed carbon	55.380
Volatile matter	28.505
Moisture	1.010
Ash	14.405
Sulphur	.700
Total	100.000
Coke	70.485

An analysis made from a sample of this coal, collected by the writer at the Clark Neal bank and analyzed by Mr. W. T. Schaller of the United States Geological Survey, is as follows:

Analysis of Lower Freeport coal on Neal Run.

	Per cent.
Fixed carbon	60.50
Volatile matter	29.17
Moisture	1.52
Ash	8.81
Sulphur	1.69

Color of ash, white. It is a good coking coal.

UPPER FREEPORT COAL.

The "four-foot coal," as it is called, has an extensive exposure in this quadrangle. Its outcrop is to be found in all four corners and well in toward the middle of the area. By far the longest line of out-

crop is in the northwest quarter of the quadrangle, where the coal is above water level on every tributary of Crooked Creek. The average thickness of the bed is probably a little under 4 feet, and the coal is everywhere somewhat slaty and sulphurous. The areas in which the coal outcrops are so detached that they may well be described separately.

Southeast quarter.—The Upper Freeport coal is brought to the surface in the southeast corner of the quadrangle by the Jacksonville anticline. The axis of this fold in the geologic structure crosses Conemaugh River half way between Saltsburg and Tunnelton with a strong northeast trend. It turns northward near Lewisville and passes 1 mile west of Jacksonville, pursuing a course nearly parallel with Reeds Run, and disappearing soon after entering the Indiana quadrangle near Tannery. The coal is exposed along the whole length of Coal Run, and on Aultmans Run northward from the mouth of Coal Run to the headwaters of Neal and Reeds runs. The bed has been opened at short intervals north and south of Jacksonville and shows a thickness ranging from 3 feet 6 inches to 4 feet 7 inches. An average thickness for the coal in this vicinity is 4 feet, the typical section, measured on Coal Run by the Second Survey,[a] being as follows (fig. 2, *G*):

Section at Kennedy's mine on Coal Run.

	Ft.	in.
Coal	3	2
Bony coal and slate	0	3
Coal	0	6
Total	3	11

In an opening at the western head of Coal Run the bed was seen 4 feet 7 inches thick, while on the northern branch of the same stream near the road forks, 1 mile due west from Jacksonville, the coal seen in a new test pit measured 3 feet 6 inches. On Aultmans Run the bed is 4 feet thick on the following farms: McKee, Fails, Jacks, Means, McFarland, Evans, and McIntyre. It measures 3 feet 11 inches on the Clawson farm and at a point 2 miles northeast of Jacksonville on a tributary of Aultmans Run; 3 feet 10 inches at George Dickey's; and 3 feet 10 inches to 4 feet in the A. W. Robinson bank and the abandoned workings near the head of Reeds Run. Near the mouth of Reeds Run, where the Lower Freeport coal has an unusual development, the Upper Freeport, 60 feet above it, is from 4 feet to 4 feet 3 inches thick.

The Upper Freeport coal with its underlying limestone is also exposed for more than a mile at the upper end of Marshall Run, in which distance it rises 170 feet on the flank of the Jacksonville anti-

[a] Second Geol. Survey of Pennsylvania, Rept. HHHH, p. 248.

cline. There are a number of openings on the coal in this ravine, but they were so badly caved that no measurements of the coal could be made.

It is known that the Upper Freeport coal is thin in the southern central part of Young Township, where it lies deep below the surface.

Southwest quarter.—The Elders Ridge syncline carries the Upper Freeport coal several hundred feet below the surface. Well records show that at the mouth of Blacklegs Creek it is 320 feet and at the mouth of Long Run 250 feet below water level. If the interval between the Pittsburg and Upper Freeport coals remains the same as on the river, the latter coal should be about 800 feet below the village of Elders Ridge.

The Roaring Run anticline brings the Allegheny formation to the surface again on the western side of the quadrangle. The Upper Freeport coal appears in the Kiskiminitas River at Salina with a thickness of 3 feet 10 inches, but at a point less than a mile downstream it is seen 130 feet above the water, and 4 feet 5 inches thick.

In the valley of Roaring Run the bed has a thickness of 4 feet (fig. 2, *H*), which it maintains with great persistency. It carries a small parting, which usually is not more than 1 inch thick. The outcrop extends to the head of the run near Shady Plain and shows numerous openings along the entire length of the stream in this quadrangle. Many of these were abandoned, however, because the coal dips into the hills on both sides of the valley and is difficult to drain.

In the bank on the Hilty Brothers' farm, near the mouth of a small run three-fourths of a mile south of Equitable, the bed is 4 feet 5 inches thick at the entrance, but diminishes to a little less than 4 feet at the breasts farther up on the anticline. In one or two banks on the west side of the run the coal was seen 3 feet 10 inches thick, and it is reported to be a little over 4 feet thick in the pits near the head of the run, but these have been abandoned and the statement could not be verified. An abundance of natural gas in this region may account in part for the abandonment of some of the coal pits.

There is a very limited outcrop of the Upper Freeport coal in a small ravine on the Grey farm 1 mile northwest of Long Run. The stream has cut into the flank of the Roaring Run anticline just deep enough to reveal the coal for a few rods. The dip is nearly 6 degrees and carries the bed under water level before reaching the mouth of the little branch. Up the ravine it disappears under the hill no less quickly. Two sections are given, the first of which was measured by the writer at the lowest opening, and the second was published by the Second Survey in the report on Armstrong County.[b] (Pl. V, *A*, *B*.)

[b] Second Geol. Survey of Pennsylvania, Rept. H5, p. 38.

Sections on Grey farm.

	Section 1.	Section 2.
	Ft. in.	Ft. in.
Coal	1 3	.....
Parting (bony coal)	0 2	0 3
Coal	0 10	3 3
Parting	1 3	2 4
Coal	3 8	2 0
Total	7 2	7 10

The arrangement in the sections given above is not intended to represent correlations. It is possible that the lowest coal bench is the same and that the heavy parting above it may be correlated, but it does not seem probable that the middle coal in the first section represents the heavy bench in the second section. It is more likely that the 2-inch parting in the first section did not occur in the opening where the second section was measured and that the upper and middle benches of coal, with this thin parting—in all, 2 feet 3 inches thick—are to be correlated with the 3 foot 3 inch bench. The thickness of the main parting makes recovery of all the coal expensive by reason of the large amount of waste which must be handled.

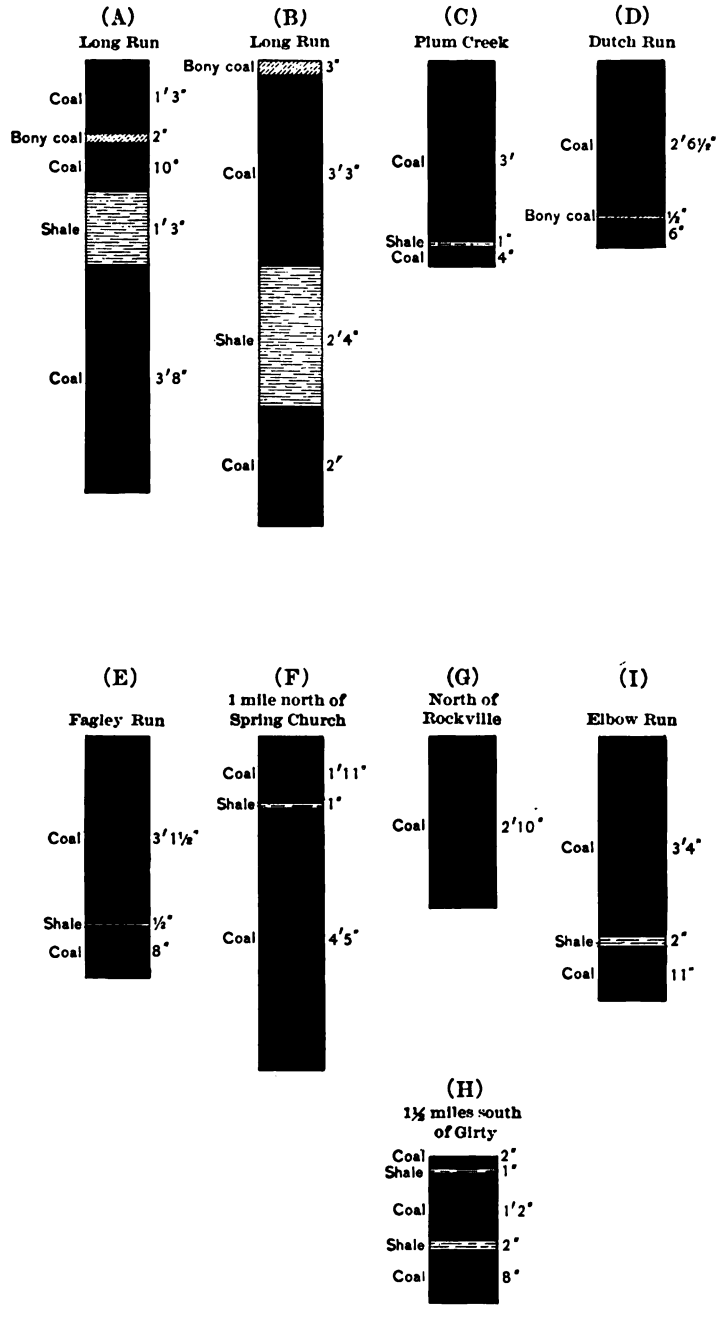
Northeast quarter.—On the South Branch of Plum Creek the Upper Freeport coal is exposed just above water level for 3 miles by the uplift of the Dutch Run anticline. One mile of this outcrop is on the Elders Ridge quadrangle and the other two extend up to Willet, on the Indiana quadrangle. The coal on this stream measures from 2 feet 10 inches to 3 feet 6 inches in thickness. The following section shows the condition of the bed in the Parke and Trusal mines on Sugarcamp Run, 2 miles east of the boundary of this quadrangle, and so closely resembles the section in the Marlin bank at Willet, published by the Second Survey, that it may be considered fairly typical for the occurrence in this corner of the quadrangle (Pl. V, *C*):

Section on Sugarcamp Run.

	Ft.	in.
Coal	3	0
Shale	0	1
Coal	0	4
Total	3	5

A sample from the upper or main bench of the bed in the Marlin pit was analyzed by Mr. McCreath,[a] with the following results:

[a] McCreath, A. S., Second Geol. Survey of Pennsylvania, Rept. HHHH, p. 281.



SECTIONS OF UPPER FREEPORT COAL.

Analysis of Upper Freeport coal on Sugarcamp Run.

	Per cent.
Fixed carbon	60.736
Volatile matter	31.890
Moisture	1.100
Ash	4.995
Sulphur	1.279
Total	100.000
Coke	67.01

The Upper Freeport coal is also exposed for 1½ miles on Dutch Run, and on Plum Creek to its mouth, with an average thickness of little more than 3 feet. There is a coal bank on the Ramsey farm on Dutch Run which is operated by Mr. Jacob Miller. The bed varies in thickness from 2 feet 9 inches to 3 feet 1 inch, including one half-inch bony parting about 6 inches from the floor (Pl. V, *D*). It is reported that the coal is 4 feet thick in some parts of the old workings. In the winter of 1902–3 the bank was operated by three men from fall to spring, and from 25,000 to 28,000 bushels of coal were sold at 4 cents a bushel on the scaffold.

The coal pits on Plum Creek below Elderton are mostly closed. The most extensive mining seems to have been done on the Clark and Ralston farms, where there are several old pits near each other. In a coal bank at the bend on Crooked Creek, a half mile above the mouth of Plum Creek, the bed was seen 2 feet 6 inches thick. The coal is carried below water level at this point by the Elders Ridge syncline and reappears 8 or 9 miles east of here at Chambersville on Crooked Creek and at Ernest on McKee Run.

The horizon of the Upper Freeport is just above water level at the big bend of Crooked Creek, a half mile below Idaho, and several openings were once made on the coal at the base of a conical hill which stands between the present and the former course of the creek. The thickness of the coal or the extent of the workings could not be determined because the pits had all fallen in.

Northwest quarter.—The Upper Freeport coal is widely exposed in this quarter of the quadrangle. It is raised above water level a half mile below South Bend by the Roaring Run anticline and continues in sight to Allegheny River. The elevation of the formation is sufficient to carry the outcrop of the coal up the tributaries of the creek for long distances. In the vicinity of Girty, on the north side of Crooked Creek, the bed measures from 3 feet 4 inches to 3 feet 6 inches in a number of banks. On Fagley Run, in the George Altman bank (Pl. VI, *A*), the coal is 3 feet 10 inches thick with ½-inch bearing-in slate 8 inches above the floor (Pl. V, *E*). At the present breast, which is 500 feet from the entry, the face is 3 feet 7 inches high.

On the south side of Crooked Creek there is an area near Girty in which the Upper Freeport coal is thinner than usual. On Barrel Valley Run, which has its mouth just above Girty, the bed is reported to be 2 feet 6 inches thick on the Watson and Painter farms. In a little pit back of the schoolhouse and church on this run 1½ miles south of Girty the following section was measured (Pl. V, *H*):

Section south of Girty.

	Ft.	In.
Coal	0	2
Shale	0	1
Coal	1	2
Shale	0	2
Coal	0	8
Total	2	3

This condition seems to be local, however, for the coal is 3½ feet thick on the Marshall farm 1 mile northeast of Shady Plain, and 4 feet 8 inches at James Clark's above Mateer. There are a number of pits near Mateer in which the bed is from 3½ to 4½ feet thick.

On Carnahan Run, 1½ miles north of Spring Church, this coal has been mined extensively on the farm of the Clark heirs and adjoining farms a half mile east of the schoolhouse, and shows a considerable thickness (Pl. V, *F*):

Section 1½ miles north of Spring Church.

	Ft.	In.
Coal	1	1
Shale	0	1
Coal	4	5
Total	5	7

At Cochran Mills the Upper Freeport coal is near the top of the bluff and has been opened in only a few places. The bank on the Samuel Fiscus farm is worked every winter. The product in the winter of 1902–3 amounted to 9,000 bushels, which was sold on the scaffold at 3½ cents a bushel. The coal is 3½ feet thick in this bank and rises both to the right and left of the entry. On Cherry Run there are a number of openings in which the coal measures 4 feet. Near Adam Cessna's it is about 3 feet 9 inches and at Joe McKee's 4 feet 2 inches.

It will be seen by the economic geology map that the Upper Freeport coal is above water level on the North Branch of Cherry Run in the vicinity of Rockville. Mr. Platt stated in the Second Survey report on Armstrong County that the coal goes under the run at Heilman schoolhouse, Rockville, and that the Gallitzin seam is opened at Remaley's mill, between Rockville and Shay. He describes the Gallitzin seam as being 2 feet 7 inches thick 50 feet above the Upper Freeport coal and resting on massive Mahoning sandstone. The pres-

A. TYPICAL COAL BANK ON FAGLEY RUN.

B. PITTSBURG GAS COAL COMPANY'S HEADING NO. 2, HARPER RUN.

ent writer came to the conclusion that the Upper Freeport coal continues above water level at Rockville and decreases in thickness from 42 inches near Pyrra to 22 inches or less at Remaley's mill. The heavy sandstone which outcrops at Rockville is believed to be the Butler sandstone. The Mahoning sandstone may be seen above the Upper Freeport coal at Remaley's mill. This mill is now owned by Mr. Heffelfinger.

It is generally admitted that the coal which outcrops just above water level at Pyrra is the Upper Freeport. The rocks rise to the northwest on the Greendale anticline, and the coal keeps above the stream to Remaley's mill, shown by the following occurrences, with their approximate el .ons above sea level:

Elevations of Upper Freeport coal above sea level.

	Feet.
Abandoned coal bank near Pyrra	1,045
Van Schall coal bank (coal 42 inches)	1,050
Coal blossom reported plowed up on hillside	1,070
Wet spring spots opposite Reuben Schall's	1,085
Old opening below Crim's house	1,110
Old opening below Crim gas well	1,120
New opening below Remaley's mill (coal 22 inches)	1,130
Old opening above Remaley's mill (coal 18 inches to 3 feet)	1,150

The coal bed which has been opened at Remaley's mill has been mined in several places on Cherry Run north of Rockville. On the Harry Faith farm four pits have been dug, only one of which is accessible. This shows 2 feet 10 inches of clean coal (Pl. V, *G*). A half acre of coal is said to have been mined on the Schall and Heilman farms in a period of thirty years. The bed is said to have averaged 2 feet 4 inches of clean coal, but as the bank was abandoned ten or twelve years ago this statement could not be verified. If the coal above the run at Rockville is Upper Freeport this also is. The writer believes that the coal bed reported at a depth of 15 to 20 feet below the run in wells drilled at Rockville is the Lower Freeport. Its thickness is not known.

On Elbow Run, 1½ miles from Crooked Creek, both the Upper and Lower Freeport coals are reported to have been opened or stripped many years ago and found to be 3½ feet thick. There was no opportunity to verify this statement. In the Robert Walker bank near the mouth of Elbow Run this section was measured (Pl. V, *I*):

Section on Elbow Run.

	Ft.	in.
Coal	3	4
Shale	0	2
Coal	0	11
Total	4	5

On Big Run, which is in the northwest corner of the Elders Ridge quadrangle and heads near Shay, the Upper Freeport has been opened in a number of places on the Daniel Campbell and Samuel McClune farms. Thousands of bushels of coal have been taken out, but the industry was given up about 1893 on account of trouble with miners and because gas was discovered in the neighborhood about that time. Mr. McClune says that the coal measures from 4 feet to 4 feet 9 inches and carries very little shale parting.

The composition of the Upper Freeport coal is shown by the following analyses. The first was made by A. S. McCreath for the report of the Second Survey on Indiana County. The sample was taken from the upper bench in the Hazlett mine near Jacksonville. The second analysis was made by E. C. Sullivan, of the United States Geological Survey, from a sample of marketable coal in the Walker mine on Crooked Creek near the mouth of Elbow Run. The third and fourth analyses were made by W. T. Schaller, of the United States Geological Survey, from samples of marketable coal taken by the writer in the George Altman bank on Fagley Run north of Girty and the A. W. Robinson bank at the head of Reeds Run north of Jacksonville.

Analyses of Upper Freeport coal.

	Hazlett.	Walker.	Altman.	Robinson.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Fixed carbon	56.679	51.23	59.57	58.94
Volatile hydrocarbons	26.500	37.76	29.43	29.26
Moisture	1.180	1.23	2.43	1.47
Ash	14.970	9.78	8.57	9.63
Sulphur	.671	3.94	.80	2.25

PITTSBURG COAL.

OCCURRENCE.

The northernmost remnant of the Pittsburg coal seam, which underlies about 2,000 square miles in the southwestern part of Pennsylvania (fig. 3), is in the Elders Ridge quadrangle. This remnant is a small area which lies along the Armstrong-Indiana county line and is detached from the main body of the seam.

EXTENT.

Geographically the limits of the Elders Ridge coal field are clearly defined. It is bounded on the north by Gobblers Run, on the east by Blacklegs Creek, on the south by Kiskiminitas River, and on the west by Long Run. It is about 10 miles long and 3 miles wide,

with the long axis in a northeast-southwest direction. This belt of coal is divided transversely into three large blocks by the valley of Whisky Run and Big Run, which have cut through the horizon of the coal and expose long lines of outcrop on both sides of the streams. The middle one of these three blocks, which lies between Olivet and Clarksburg, is the largest, and the northernmost is the smallest. All three have irregular outlines. There are a number of outliers of a few

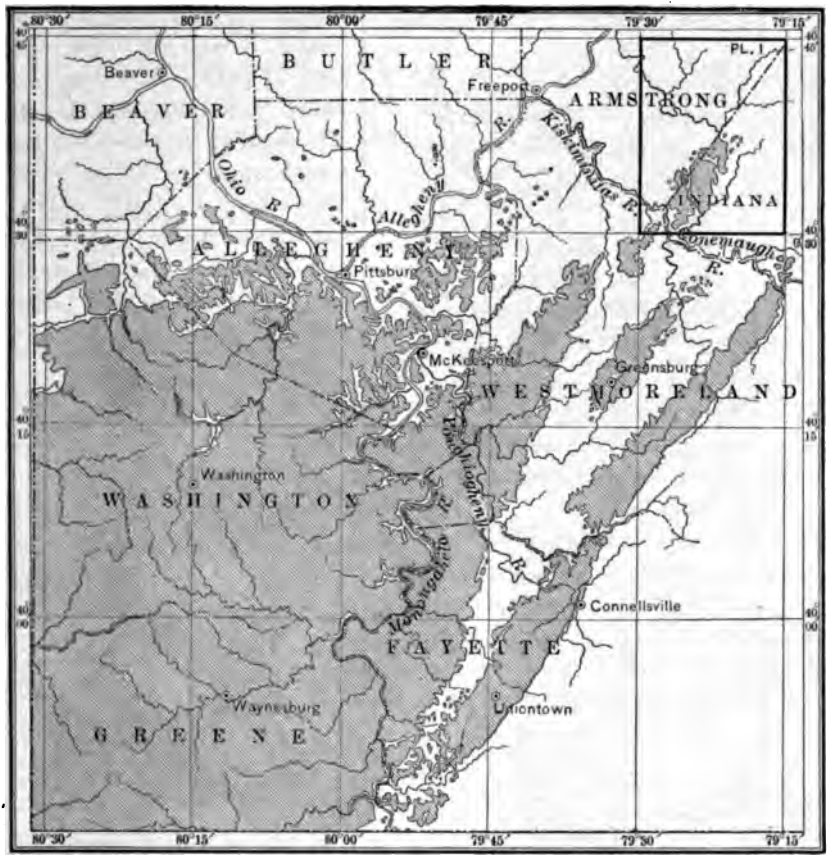


FIG. 3.—Map showing the area of the Pittsburg coal in Pennsylvania (Elders Ridge quadrangle shown by rectangle in upper right corner).

acres in extent on the northern and western sides of the field. Roughly estimated, there are about 14 square miles of coal in this area, or between 8,500 and 9,000 acres. The coal has been mined out from 600 or 700 acres. The thickness of the bed will average close to 7 feet.

STRUCTURE OF THE PITTSBURG COAL.

This coal field lies in a structural basin known as the Elders Ridge syncline. The position of the axis is shown on the accompanying

sketch map (fig. 4). It crosses the river above Edri, passes close to the Foster mine (No. 12), a few rods east of the Robert Fritz bank (No. 8), and through Elders Ridge near the academy. It enters the northern block between the W. B. Davis and John D. Hart heirs banks (No. 6), passes west of West Lebanon, and leaves the field near Holsten Brothers bank (No. 1). The beginning of the sharp deflection to the east, which takes the axis to Crooked Creek, nearly 2 miles east of Shelocta, is shown north of the coal banks on the Hugh Blakley (No. 2) and Madison Craig (No. 3) farms. All of the coal on the east side of this syncline rises toward Blacklegs Creek, and all on the west toward Long Run. The basin is deeper in the vicinity of Elders Ridge than at Edri or West Lebanon, so that the structural shape of the field is a broad canoe-like fold, with the rocks dipping from all sides toward the center. The dip is gentle, being just enough to aid the operations of the miner.

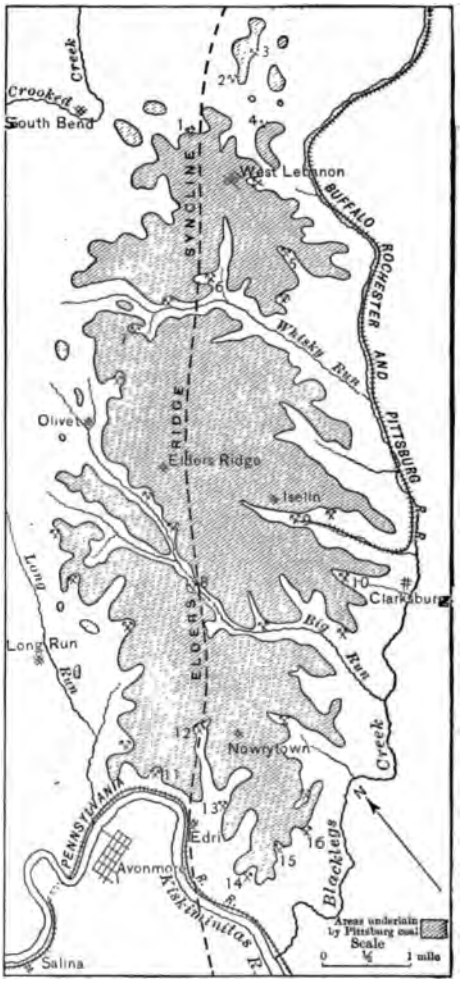


FIG. 4.—Map of the Elders Ridge coal field, Pennsylvania.

The profile of the axis of the basin is shown by the elevations of the Pittsburg coal above mean sea level. From the northeast to the southwest along the bottom of the syncline the elevations at six points are as follows:

Elevations of Pittsburg coal above sea level.

	Feet.
Holsten Brothers, No. 1	1,180
John D. Hart, No. 6	1,112
Elders Ridge, deep well near creamery	1,070
Robert Fritz, No. 8	1,022
Foster, No. 12	1,100
West side of Kiskiminitas River	1,150

This shows that the deepest part of the syncline lies between Elders Ridge and the point where the axis crosses Big Run. The axis rises

slowly from Big Run to the northeast, but more rapidly from the Fritz farm to Foster, the coal rising in this direction about 60 feet in little more than a mile.

DEVELOPMENT OF THE PITTSBURG COAL.

On the accompanying sketch map of the Elders Ridge coal field most of the points where a clean face of the Pittsburg coal may be seen are indicated by crossed hammers, the usual symbol for a mine or quarry. Some of these are numbered, for ready reference, as follows:

List of properties where exposures of Pittsburg coal occur.

1. Holsten Brothers.
2. Hugh Blakley.
3. Madison Craig.
4. Wilson Blakley.
5. Harry Hart.
6. John D. Hart.
7. Simon Townsend.
8. Robert Fritz.
9. Pittsburg Gas Coal Company.
10. Thomas Hart.
11. Avonmore mine.
12. Foster mine.
13. Edri mine.
14. Bowman mine.
15. Conemaugh Coal Company.
16. Mrs. Arnold.

For figures in parentheses in the text see fig. 4.

A large number of openings have been made on the outcrop of the coal. Many of these were abandoned after a small quantity of coal had been taken out, and have been closed for years. Other banks to the number of ten or twelve are kept open and are operated by one or two men throughout the greater part of the year. Among these country banks are those of Holsten Brothers, Madison Craig, Wilson Blakley, John D. Hart, Harry Hart, Robert Fritz, Samuel White, McComb, Thomas Hart, and John Hart. These small banks supply fuel for only a narrow belt of farms, because the Upper Freeport coal is mined on Roaring Run and on Crooked Creek below South Bend less than 2 miles west of this field, and both the Upper and Lower Freeport coals are mined to the east not more than 3 miles from Blacklegs Creek.

Extensive mining has been done only near the river. Between forty and fifty years ago, when there was a canal along the river, a large mine was worked on the Rhea property, near Avonmore, but developments here terminated about 1865, when the Western Pennsylvania division of the Pennsylvania Railroad was built and the canal was abandoned. Coal mining on a large scale began again about fifteen years ago, and at present there are five or six mines which ship their output to distant markets by rail.

The Avonmore mine (No. 11), which is operated by the Avonmore Coal and Coke Company, is situated at Hicksville on the bluff 350 feet above the river. The working faces are from one-half to three-fourths of a mile from the mine mouths. The cars are collected in the mine by mules and hauled out to the top of the bluff by cable; they

are lowered to the tipple on the railroad by a double-track gravity incline. A daily output of 500 tons is made with a force of 150 men. L. W. Hicks, of Leechburg, Pa., is superintendent of the company. This mine has been working continuously since 1889 (Pl. VII, *A*).

The Foster mine (No. 12) is owned by the Saltsburg Coal Company and was reopened in the fall of 1903 after standing idle a number of years. The coal is hauled down the run and around the face of the river bluff to the tipple on the railroad by a narrow-gage steam locomotive. In December, 1904, this mine was producing 750 tons per day. At the Edri mine (No. 13), which is situated on the hill east of the station of that name, the cars are brought out by mules, and lowered about 200 feet to a tipple on a spur from the railroad. A double-track gravity incline is the method for lowering and raising cars. About 50 men are employed and the daily output is 200 tons. This mine is operated by the Edri Coal Company.

The Bowman Coal Mining Company, S. J. Robinson, superintendent, operates a mine (No. 14) near the southern extremity of the field on the hill about three-fourths of a mile south of Edri. The company employs 60 men and ships from 200 to 250 tons daily. Mules are used for hauling the coal from the breast out to the brow of the hill (Pl. VII, *B*), where it is lowered by an incline to a railroad tipple.

The Conemaugh Coal Company, of Blairsville, Pa., F. M. Graff, superintendent, in 1903 opened a mine (No. 15) a half mile east of the Bowman Company mine. There were 100 men on the pay roll in December, 1904, and they were getting out about 7,000 tons per month. Almost 1,000 feet of heading per month were being driven in the fall of 1904, and it is expected that an additional capacity of 1,000 tons will soon be developed. A large tipple has been built over a railroad spur at the sheet-steel mill and cars are handled on the incline by steam power.

The Pittsburg Gas Coal Company has started a new coal town on Harper Run, about 1¼ miles south of Elders Ridge. This company began operations in the summer of 1903 by building a dam across the run, erecting power houses, and starting 6 headings on the coal (Pl. VI, *B*, p. 40). Three of these headings are on the east side of the run and have natural drainage. The other 3, on the west side of the run, are down the dip of the rocks, so a heading is being run almost due west to Big Run to give natural drainage to all the workings in that part of the mine. Electric haulage and all modern improvements, both inside and outside, are used at this mine.

The company expects to erect 350 to 400 houses on its town site, known as Iselin. In March, 1905, according to John Reed, assistant general manager, the town had a population of 2,000, and the company was employing 400 men and producing 1,850 tons of coal daily.

A. AVONMORE MINE, HICKSVILLE.

B. ENTRANCE TO BOWMAN COAL COMPANY'S MINE.

The Buffalo, Rochester and Pittsburg Railway has been extended from Creekside, Indiana County, to Iselin. It began hauling coal from this mine in August, 1904.

THICKNESS OF THE PITTSBURG COAL.

The Pittsburg coal bed in the Elders Ridge field is slaty and much parted in some places; in others it is clean and almost unbroken. It varies in thickness, including its partings and roof coal, from 7 to 10 feet. Generally the roof coal is not taken, being so much parted by thin bands of shale that it has little value. Moreover the shales over the roof coal are so soft and friable that the coal has to be left to support them. The bed has been opened at a great many places in this basin, but there are hardly more than twenty localities where accurate measurements of the seam can easily be made. A few measurements are given in detail to show the character of the seam.

Northern block.—That portion of the Elders Ridge field which lies east of Whisky Run is the smallest of the three blocks into which the field is divided. The small outliers of a few acres in extent which are seen near West Lebanon are the most northern remnants of the great Pittsburg coal bed. Beyond this point the bed would be carried above the present surface by the rising axis of the Elders Ridge syncline if projected beyond the outcrop.

About two-thirds of a mile north of West Lebanon Holsten Brothers own a coal bank (No. 1), which was opened many years ago, but has been worked actively only since about 1900. The coal dips southeast and is practically free from partings and horsebacks. The section is as follows (Pl. VIII, *A*):

Section at Holsten Brothers coal bank.

	Ft.	In.
Coal	2	2
Shale and coal	0	4
Coal	2	5
Shale	0	½
Coal	2	2
Total	7	1½

In a small outlier of the coal, a short distance east of West Lebanon, Wilson Blakley owns a bank (No. 4), which is being worked by H. L. Dillinger. The coal in this bank shows the following thickness (Pl. VIII, *B*):

Section at Wilson Blakley coal bank.

	Ft.	In.
Coal	1	8
Shale	0	11
Coal	3	11
Shale	0	1
Coal (seen)	1	3
Total	7	10

In the fall of 1903 this bank was delivering 2,500 bushels a month to the steam shovels working on the Buffalo, Rochester and Pittsburg Railroad cut near Parkwood, and the Madison Craig bank (No. 2) was working on a similar order.

These northern banks in the Elders Ridge field furnish a large part of the local supply in the Crooked Creek Valley. Being compact and hard, the Pittsburg coal comes out of the mine in firm blocks, which in spite of their impurities are preferred by the farmers for use in stoves and grates to the softer coal from the Upper Freeport seam as mined on Crooked Creek.

At the J. D. Hart bank (No. 6) on Whisky Run, 1 mile southwest of West Lebanon, the entire thickness of the coal was not seen. Two bands of roof coal, 8 and 3 inches thick, are said to be above the draw slate and are not taken down. The main part of the seam comprises 5½ feet of good coal with only two thin partings (Pl. VIII, *C*).

Partial section of J. D. Hart coal bank.

	Ft.	in.
Coal	1	8
Shale	0	½
Coal	1	8
Shale	0	1
Coal	2	1
Total	5	6½

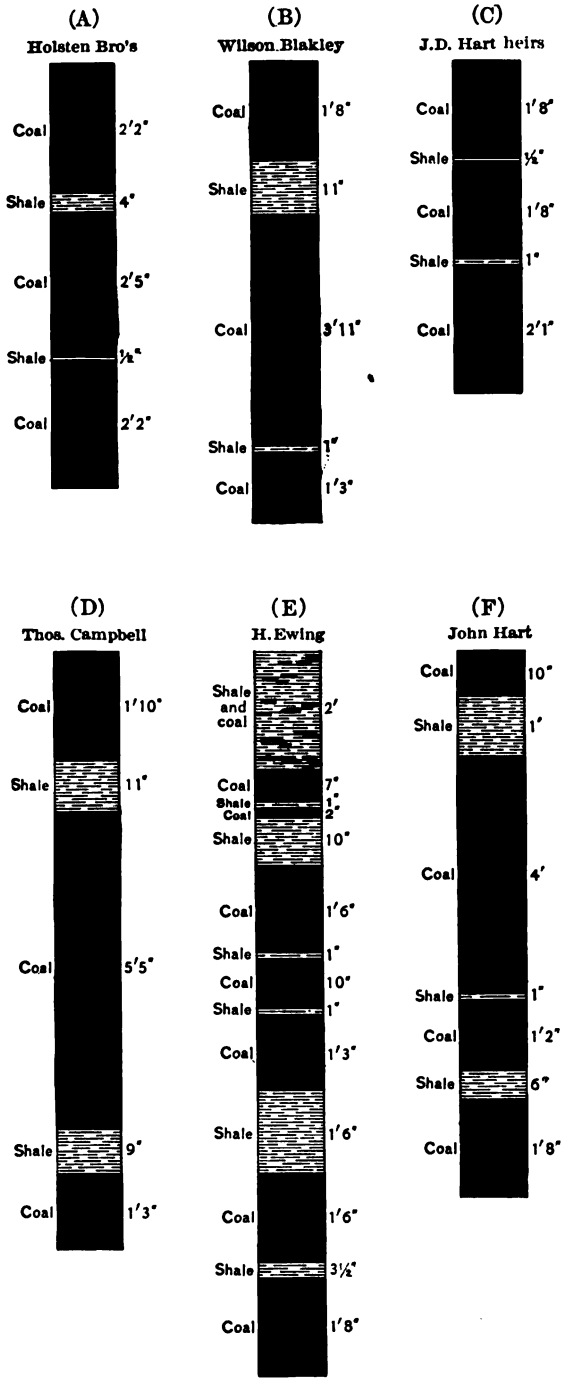
The thickest section of Pittsburg coal measured by the writer is in this northern block, on the farm of Thomas Campbell. Back of his house, which is 1½ miles south of West Lebanon, there is a small ravine in which the coal is well exposed and headings have been driven. The seam is in three benches, the middle one being nearly 5½ feet thick. The section is as follows (Pl. VIII, *D*):

Section on Thomas Campbell farm.

	Ft.	in.
Coal	1	10
Shale	0	11
Coal	5	5
Shale	0	9
Coal	1	3
Total	10	2

Middle block.—Under this heading is included all that portion of the field which lies between Big and Whisky runs. Sections at all of the working banks can not be given, and four or five will be enough to show the variable characters of the bed.

Twenty-five years ago the local trade about Elders Ridge was supplied by a pit on the H. Ewing farm. This coal pit was a short distance east of the Simon Townsend bank (No. 7). Here the bed is at



SECTIONS OF PITTSBURG COAL.

its thickest, and the following detailed section was measured by the Second Geological Survey of Pennsylvania (Pl. VIII, *E*):

Section at the Ewing coal bank.

Roof division:	Ft.	In.
Slate and coal	2	0
Coal	0	7
Slate	0	1
Coal	0	2
Slate and clay, main parting	0	10
Coal	1	6
Slate	0	1
Coal, slaty	0	10
Slate	0	1
Coal	1	3
Slate, 4 inches to	1	6
Coal	1	6
Slate, ½ inch to	0	3½
Coal	1	8
Slate	--	---
Total	12	4½

The seam shows more slate partings than is usual, and the coal in the different benches is said to be slaty and poor. This much-parted condition of the seam may be local, however.

The Pittsburg coal is mined on Harper Run by John Hart. A section obtained there shows all of the bed except perhaps a thin layer in the roof shales. The following measurement was made (Pl. VIII, *F*):

Section at John Hart coal bank.

	Ft.	In.
Coal	0	10
Shale	1	0
Coal	4	0
Shale	0	1
Coal	1	2
Shale	0	6
Coal	1	8
Total	9	3

At the new mine of the Pittsburg Gas Coal Company a measurement was made in heading No. 2. This mine is just across the run from the bank mentioned above, but shows fewer partings. The section is (Pl. IX, *A*):

Section at Pittsburg Gas Coal Company mine.

	Ft.	In.
Coal	6	6
Shale	0	6
Coal	2	0
Total	9	0

The bottom bench, which runs from 20 inches to 2 feet thick, is not being taken out at present. The great thickness of the main bench of coal promises well for the mine if the visible conditions continue. It is overlain by a draw slate which varies from 6 to 12 inches in thickness, but whether there is more coal above this or not has not been ascertained.

Mr. Thomas Hart is operating a bank (No. 10) on a small run near Clarksburg to supply local trade. The main bench of coal is 4 feet 10 inches thick, with one shale parting less than an inch thick a little above the middle (Pl. IX, *B*). The roof coal was not seen, but it is separated from the main bench by 10 inches of shale, and is at least 4 inches thick.

At the southern end of the middle block of coal in this field there is an opening on the James Crawford heirs' farm, which has not been worked for some time, but which was still accessible when seen in 1902. It showed a good body of coal in two benches, but not so thick as in an old opening on the Samuel Gailey farm, a mile farther up Big Run. The sections in these two banks are as follows (Pl. IX, *C*, *D*):

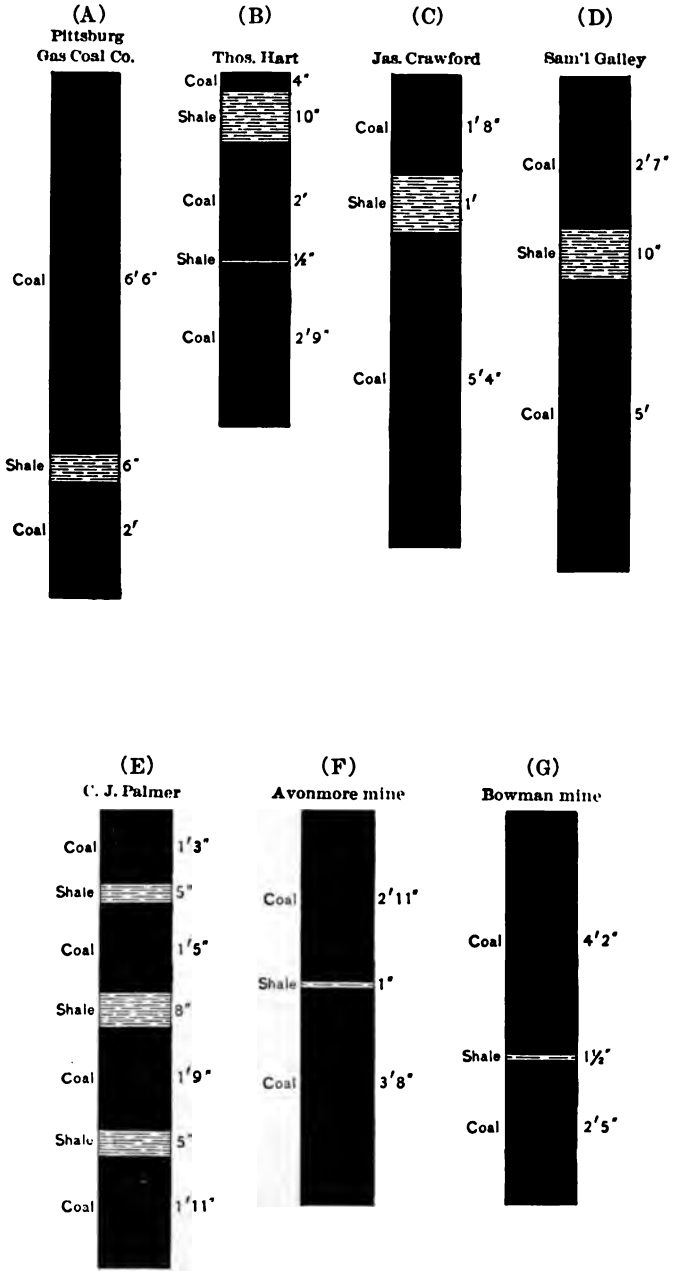
Sections on Crawford and Gailey farms.

	Crawford.		Gailey.	
	Ft.	In.	Ft.	In.
Coal	1	8	2	7
Shale	1	0	0	10
Coal	5	4	5	0
Total	8	0	8	5

A detached area of coal containing about 200 acres and lying between the forks of Big Run on the west side of the syncline has been prospected a little, but is not being mined at the present time.

Southern block.—The southern block of the coal field is very irregular in shape. It lies between Big Run and Kiskiminitas River, and by reason of its position has been mined on its river side more than in any other part of the field. The variations in the thickness of coal benches and shale partings are much the same as already described in the northern and middle blocks.

At the northern extremity of the block on the C. J. Palmer farm there is an old pit which was open although not working when seen by the writer. The section at this point is fairly typical of all that portion of the field, and compares very closely with a measurement made at a bank about 1 mile southeast of Long Run, although the latter had a few inches more of coal at the point where the seam was measured. The section at the Palmer bank is as follows (Pl. IX, *E*):



SECTIONS OF PITTSBURG COAL

Section at Palmer coal bank.

	Ft.	in.
Coal	1	3
Shale	0	5
Coal	1	5
Shale	0	8
Coal	1	9
Shale	0	5
Coal	1	11
Total	7	10

Mr. Samuel White owns and operates for country trade a bank about a mile northeast of Long Run, and Robert Fritz has an opening (No. 8) on Big Run. Complete sections were not obtained at these points, but the bed is known to be over 6 feet thick.

The Avonmore mine (No. 11) is operating on the Pittsburg seam, where the average thickness of merchantable coal is over 6 feet. The usual thickness in this mine, exclusive of the roof coal, is as follows (Pl. IX, *F*):

Partial section at Avonmore mine.

	Ft.	in.
Coal	2	11
Shale	0	1
Coal	3	8
Total	6	8

At the Foster mine (No. 12) the seam carries about the same amount of coal. The parting or "band slate" in all of these mines varies in thickness; near the river it seems usually to be only 1 or 2 inches thick, but increases in places to a foot or more. The total thickness of the bed in the Edri mine (No. 13) changes from 5 feet 9 inches to 8 feet in a few spots, where the parting thickens from 1½ inches to 3 feet.

In the Bowman mine (No. 14), at the southern end of the field, that part of the bed which is taken out is 80 inches high and contains only one noticeable parting. The section is as follows (Pl. IX, *G*):

Partial section at Bowman mine.

	Ft.	in.
Coal	4	2
Shale	0	1½
Coal	2	5
Total	6	8½

The main bench, which is over 4 feet thick, contains a very thin streak of shale, but its exact position was not noted.

Two other mines, also on the southern lobe of this block, are the new one owned by the Conemaugh Coal Company (No. 15) and the mine on the Arnold farm (No. 16), which used to supply the American Sheet

Steel Company mill at the mouth of Blacklegs Creek, but is now operated only for country trade. At the Conemaugh mine the parting or "band slate" is usually from 1 to 2 inches thick, but thickens in places to 1 foot. The "draw slate," from 6 inches to 1 foot thick, is taken down in entry, but can be held in rooms. The total thickness of coal is practically the same as in other mines at this end of the field.

Three small areas of Pittsburg coal are represented in Bell Township, west of Kiskiminitas River. In a coal bank at the road fork, 2 miles south of Avonmore, the following section was measured:

Section 2 miles south of Avonmore.

	Ft.	in.
Coal	0	4
Clay	0	6
Coal	0	3
Draw slate	2	0
Coal	7	10
	10	11

TONNAGE OF THE PITTSBURG COAL.

Allowing 1,560 tons to the acre for each foot, the Pittsburg seam, which averages 7 feet of workable coal in this field, contains 10,920 tons to the acre. There are probably 8,000 acres of merchantable coal remaining in the field, or 87,360,000 tons. If by most advantageous methods of working 70 per cent of this coal can be mined, the total product of the field as it now stands would be 61,152,000 tons.

QUALITY OF THE PITTSBURG COAL.

In the following table nine analyses of the Pittsburg coal in the Elders Ridge field are given. Four of these, made by Mr. A. S. McCreath, were published by the Second Geological Survey of Pennsylvania, in the reports on Armstrong and Indiana counties in 1878. The other five are new, and, so far as known, were published first in Bulletin No. 225, United States Geological Survey, p. 322.

The Avonmore analysis was furnished by the superintendent of the mine, and the method of sampling the coal was not stated.

The Arnold analyses were furnished by the Conemaugh Coal Company, with the statement that the samples "were taken in the usual way in which this work is done, viz, a narrow slip from top to bottom, getting in an equal amount of both bench and breast coal."

The samples for the Iselin and Holsten analyses were collected by the writer. In taking the samples a cut was made at a working face from top to bottom of that portion of the seam which is marketed. The samples were mixed and quartered and sealed in glass fruit jars. The analyses of the Iselin and Holsten coal samples were made in the chemical laboratory of the United States Geological Survey by Mr. George Steiger and Mr. Eugene C. Sullivan, respectively.

Analyses of Pittsburg coal from Elders Ridge field.

Locality.	Fixed carbon.	Volatile Matter.	Moisture.	Ash.	Sulphur.	Fuel ratio.	Coke.	Authority.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	
Avonmore ...	56.432	35.040	0.720	6.810	0.988	1.61	64.23	L. W. Hicks.
Arnold 1.....	55.17	32.99	.51	10.33	.98	1.67	66.48	C. B. Dudley.
Arnold 2.....	56.47	30.02	.63	11.83	1.02	1.88	69.32	Wuth & Stafford.
Iselin	56.34	31.48	1.76	10.42	1.25	1.79	68.01	Geo. Steiger.
Ashbaugh ...	53.639	37.555	1.110	6.260	1.436	1.43	61.335	A. S. McCreath.
Ewing	50.230	36.900	.800	9.030	3.040	1.36	62.30	Do.
Evans 1.....	50.850	36.940	1.040	9.705	1.465	1.38	62.02	Do.
Evans 2.....	53.788	31.995	1.460	11.760	.997	1.68	66.545	Do.
Holsten	56.25	33.41	1.61	8.73	1.87	1.68	66.85	E. C. Sullivan.

The Avonmore analysis, furnished by Mr. L. W. Hicks, superintendent of the Avonmore Coal and Coke Company, shows that the coal in the Avonmore mine (No. 11) runs high in fixed carbon and low in ash in comparison with that from other parts of the field. Although the fuel ratio is not high, the total amount of combustible matter is the highest of the nine samples. The percentages of sulphur and of ash are both very low, and the amount of phosphorus in this sample was 0.010 per cent. Judging from the above analyses alone, it is evident that the coal in the Avonmore mine is the best in the field for steaming purposes.

The Conemaugh Coal Company has furnished, through Mr. F. M. Graff, superintendent, two analyses of the coal in the Arnold mine (No. 16), one made by C. B. Dudley, of Altoona, the other by Wuth & Stafford, of Pittsburg, Pa. Both analyses run high in ash and low in moisture. Arnold 2 runs higher in fuel ratio than any other sample from this field. This is due to a low percentage of volatile matter. It also shows the highest per cent of coke. The high ash, however, keeps this from being the best sample in the above list. Arnold 2 shows a phosphorus content of 0.028 per cent.

The Arnold mine has about 8 acres of coal, and lies within a few hundred feet of the main entries of the Conemaugh mine. The Conemaugh Coal Company owns the coal all around it, and these Arnold analyses probably represent the character of the immediately surrounding coal.

The Iselin analysis was made from a sample collected by the writer in No. 2 heading of the Pittsburg Gas Coal Company mine (No. 9) at Iselin. It shows the composition of the coal of the main bench, 6½ feet thick, which is now being taken out. The percentage of ash and moisture is high, but the fuel ratio is excellent. The coke per cent and total amount of combustible matter are high. Nine tons of this coal sent to Adrian to be tested made a good coke.

The Ashbaugh analysis, published more than twenty-five years ago, is from a sample of the coal taken at Ashbaugh's steam mill on Har-

per Run, 1 mile above Clarksburg. The lower bench of the bed has a cannel appearance and is very rich in hydrocarbons, which probably accounts for the high percentage of volatile matter. The location is very near the new mine of the Pittsburg Gas Coal Company, but the analyses of the coal at the two points differ considerably. The Ashbaugh analysis shows the next highest amount of combustible matter of any locality in the field.

The coal of the Ewing bank in all the different benches is slaty and poor. Some of it is overloaded with iron pyrites, and none of it in its raw state could be considered marketable fuel, except for local supply. Although not the lowest in total amount of combustible matter, it is the lowest in fuel ratio, and carries such a high percentage of sulphur as to make it unsalable for many purposes.

At the mill of Mr. J. Evans, close to West Lebanon, the Pittsburg coal was mined many years ago. The bed is somewhat slaty and more pyritous than at most other localities. Mr. McCreath analyzed a specimen representing about the average run of the main benches, and the results are given in the table above as Evans 1. One bench (that next to the lowest) in this bank assumes a cannel appearance and Evans 2 is an analysis of the same.

The coal in the Holsten bank (No. 1) takes third place in the list for total amount of combustible matter, stands high in fuel ratio and coke per cent, and it is also high in sulphur. The analysis of the coal at this bank was made by Mr. Eugene C. Sullivan, of the United States Geological Survey, from a sample collected by the writer at a fresh breast.

On the basis of the analyses which give the coal in the Avonmore mine first place, there would be difficulty in making a second choice. The coal at the Holsten and Arnold pits is no better than that on Harper Run.

SEWICKLEY COAL.

The horizon of the Sewickley coal is about 120 feet above the Pittsburg, and its occurrence is limited in this quadrangle to the center of the Elders Ridge syncline. The coal is nowhere worked in this region, but the blossom is seen frequently in ditches along the roadside. It is conspicuous at the road corner above the Thomas Hart bank 1¼ miles northwest of Clarksburg, and also a few rods north of the church at Elders Ridge. An opening on the Smith farm near Elders Ridge, made many years ago, is claimed to have revealed a much-parted seam measuring 5 feet 3 inches. The coal is said to be 3 feet thick in the cliff above Hicksville, but occurrences noted do not indicate more than 2 feet.

COKE.

There are no coke ovens in the Elders Ridge quadrangle at present. It is probable, however, that some time the Pittsburg coal in this area will be coked if it proves to be adapted to the purpose. In the chemical analyses of Pittsburg coal from the Elders Ridge field, given on page 53, the coke percentage, which is the sum of the fixed carbon, ash, and sulphur, is highest in the Arnold and Iselin analyses. The analyses suggest, however, only the strength and purity, and fail to indicate the essential qualities of a good coking coal. The coking and noncoking properties of the soft coals are not yet clearly understood.

The only sure method for determining the adaptability of coal for coking is to have a quantity of it tested in a coke oven and then to make a careful study of the physical and chemical properties of the product.

Comparative analyses of coke.

	Elders Ridge.	Connellsville.
	Per cent.	*Per cent.*
Fixed cabon	90.532	89.509
Volatile hydrocarbons		.880
Moisture		.070
Ash	7.411	8.830
Sulphur	2.057	.711
	100.000	100.000

Two analyses of coke made from Pittsburg coal are given above. The first was made by A. S. McCreath from coke made in the laboratory of the Second Geological Survey of Pennsylvania by coking coal in a platinum crucible. The coal was from the Saltsburg Coal Company mine in the southern block of the Elders Ridge field. The second is the average of a number of analyses of typical Connellsville coke made by the H. C. Frick Coke Company. The amount of sulphur in the Elders Ridge coke is too high for a first-class product, but this might be remedied by washing the coal to get rid of part of the sulphur.

NATURAL GAS.

GENERAL STATEMENT.

More than 260 wells have been drilled for gas and oil in the Elders Ridge quadrangle during the past ten years, drilling having begun about 1894. Many of the wells have produced gas, some have been unproductive, but not one has found a pool of oil. The wells may be

grouped in seven more or less well-defined fields, which are known by local names. These are the Willet, Plum Creek, Say Farm, Girty, Shellhammer, Roaring Run, and Rockville fields.

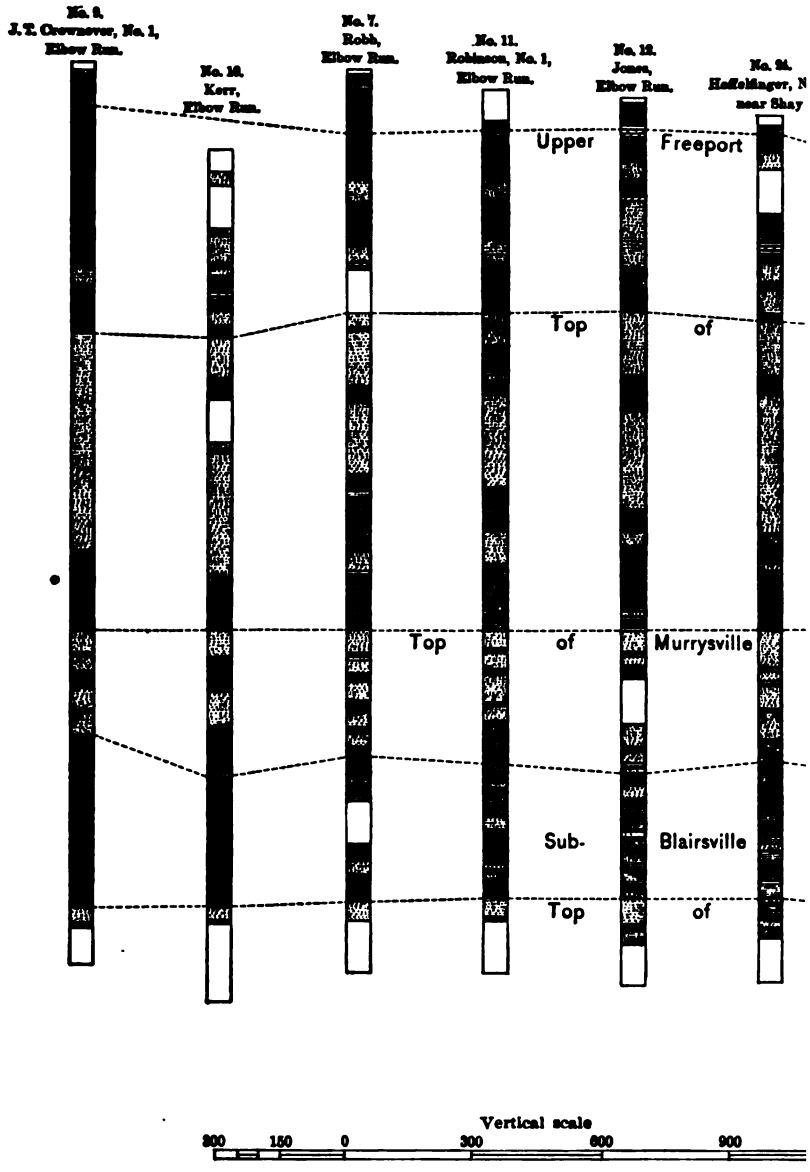
The relation of the gas fields to geologic structure appears to be definite and uniform. It will be noticed that the producing wells are near the crests or far up on the flanks of anticlinal folds, and that a number of holes located in the synclines are unproductive. Formerly it was the practice to pursue drilling operations along certain degree lines, such as N. 23° E., or N. 35° E., but now that the anticlinal theory of the accumulation of gas is generally understood, much useless work is avoided, and the direction of further drilling is determined by geologic structure rather than by compass.

Natural gas is not confined to a single horizon in the wells in this quadrangle. The Murrysville and Hundred-foot sands are the uppermost and most productive, the Pine Run and Fifth sands yield some gas, and the lowest sands—the Speechley and Tiona—also are reservoirs. Several of these sands may be found to be productive in the same well. In fact, some companies operating in the northeastern part of Armstrong County have deepened the upper-sand wells, which were fast becoming exhausted after several years of productiveness, and have found large amounts of gas in the lower sands. Early in 1904 the Philadelphia Company deepened a well which had become weak, and obtained a flow of gas with a rock pressure of over 920 pounds in the Tiona sand about 1,300 feet below the Hundred-foot sand. This is a far greater pressure than the upper sands ever have and shows the possibilities of deep drilling.

STRATIGRAPHY OF GAS-BEARING ROCKS.

The lowest rock exposed in the quadrangle is the Vanport limestone, which is in the lower part of the Allegheny formation. The following description of rocks not exposed extends from this horizon to the bottom of the deepest well, taking up the rocks in the order in which they are reached by the descending drill. The description is based on well records which have been furnished by gas companies operating in the territory. It is well known that rocks exposed at the surface change in character and thickness from place to place, and the same thing may be expected in the hidden formations. Although the vertical interval between two easily recognized beds may be approximately constant, the details in the sequence of rocks filling the interval often change materially, both in exposed sections and in well sections. For this reason it is often difficult to correlate beds in the records of wells drilled in close proximity to each other, and the author upon plotting well records to scale has not always been able to agree with the drillers in their correlations.

The records of a number of deep wells in this quadrangle are shown


No. 8.
J. T. Crownover, No. 1,
Elbow Run.
No. 10.
Kerr,
Elbow Run.
No. 7.
Robb,
Elbow Run.
No. 11.
Robinson, No. 1,
Elbow Run.
No. 12.
Jones,
Elbow Run.
No. 24.
Hafelfinger, N
near Shay
Upper
Freeport
Top
of
Top
of
Murrysville
Sub-
Blairsville
Top
of
Vertical scale
300
150
0
300
600
900

on Pls. X and XI. It must be borne in mind that the holes were churn drilled, and that the value of such records varies with the care exercised by the recorder. The correlation lines on the plates are the author's interpretation of the records, and are more or less tentative.

The record of the W. G. King well on Crooked Creek, 2 miles west of South Bend, gives a typical section of the underlying rocks of the Elders Ridge quadrangle (Pl. XI, No. 235).[a] The author has taken the liberty of using the word shale instead of slate, as in the original record, and has named the members according to his interpretation. The well began near the horizon of the Lower Kittanning coal, and was drilled by the Ford City Gas Company in February, 1892.

Record of W. G. King well, South Bend Township.

		Thickness.	Depth.
		Feet.	*Feet.*
Conductor		5	0
Sand		15	5
Shale		35	20
Limestone (Vanport)		15	55
Shale		130	70
Sand		40	200
Shale		70	240
Sand (Big Injun)		300	310
Shale		150	610
Sand		105	760
Shale		77	865
Sand		40	942
Shale and shell		23	982
Sand (Murrysville)		35	1,005
Shale		30	1,040
Sand		15	1,070
Shale		20	1,085
Sand (Hundred-foot)		50	1,105
Shale and shell		140	1,155
Red rock	Sub-Blairsville red beds	255	1,295
Shale		5	1,550
Red rock		25	1,555
Pebbly sand		7	1,580
Red rock		33	1,587
Shale		73	1,620
Depth			1,693

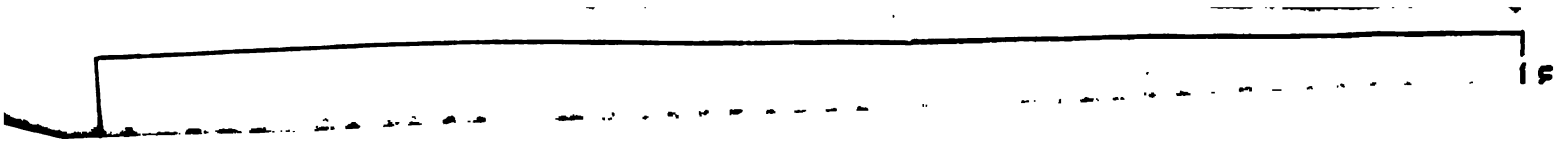
[a] Numbers in parentheses referring to deep wells indicate the location of wells on the economic geology map, Pl. I.

According to the records of a number of wells in the quadrangle, the interval between the Vanport limestone and the top of the Pocono sandstone or Big Injun sand is from 200 to 250 feet. This interval is occupied by sandstone and shale in varying proportions. Usually the lower portion is shale, and much of the sandstone probably is Pottsville. At the base of this interval in the George W. Stahl well (Pl. XI, No. 261), Conemaugh Township, is 8 feet of red rock. The color suggests that this occurrence is Mauch Chunk formation. It is possible that some of the shale shown in other well records as occurring between the Pottsville and Pocono formations is of Mauch Chunk age, although no mention of the color is made. What little Mauch Chunk may underlie this quadrangle probably is very thin. This scanty representation is interesting because of the well-known westward thinning of the formation, and of the erosional unconformity which separates the Pottsville from the underlying rocks. Farther westward, in the vicinity of Kittanning, M. R. Campbell and David White have shown that the Pottsville rests directly on the Pocono, with no intervening Mauch Chunk.

Big Injun sand.—Practically all well drillers in western Pennsylvania know the Big Injun sand, which to the geologist is the Pocono andstone. This sandstone is found from 450 to 500 feet below the Upper Freeport coal and often is from 300 to 500 feet thick. The records show considerable variation in this formation. While in one well there may be 300 feet of unbroken sandstone, other wells show large admixture of shale and shaly sandstone. In some wells shale appears less than 100 feet below the top of the formation, and the upper sand is called the 70-foot. It is the practice of some drillers to call the main sandy portion of the formation, which is separated from the 70-foot sand by a varying amount of shale, the Mountain sand. In fact, the term Big Injun is not always used. The variations in this formation can best be understood by examining the well sections on Pls. X and XI.

Patton shale member.—At the bottom of the Big Injun sand there is found in some wells, particularly in the southern part of the quadrangle, a few feet of red rock, which may be either sandstone or shale, or both. This band of red rock is between 800 and 900 feet below the Upper Freeport coal, and occupies an interval from 10 to 90 feet thick. This rock outcrops at Patton on Redbank Creek, from which occurrence Campbell has called it the Patton shale. David White has found fossils in the Patton shale which show that it is a member of the Pocono formation.

Murrysville sand.—At an approximate depth of 1,100 feet below the Upper Freeport coal a sand rock which often carries gas is found throughout this quadrangle. This is the Murrysville sand, which takes *its name from* a village of that name in Westmoreland County, where a



strong gas pool was discovered at this horizon. Other names which are used in Armstrong County for the sand are Butler sand and Salt sand. The thickness of the Murrysville sand, based on drillers' recognition, varies from 20 to 105 feet, and 69 records give an average thickness of 64 feet. The top of the Murrysville sand is usually about 700 feet below the top of the Big Injun. The interval between it and the Big Injun or the Patton shale member, when the latter is present, is filled in some wells entirely with sandstone, in others with shale or sandy shale, and in others with all three types of rocks.

Hundred-foot sand.—From 100 to 125 feet below the top of the Murrysville sand, and separated from it by a varying amount of shale, is the Hundred-foot sand. The name is derived from its thickness, which, although it varies from 35 to 150 feet, in the record of 51 wells averages 94 feet. This sand also is a gas producer. Immediately below the Hundred-foot, and separated from it by a few feet of shale, the drillers sometimes recognize a sand known as the Thirty-foot. The term is used but little in the Elders Ridge quadrangle, but is common in the records of wells in the Rural Valley quadrangle on the north. This sand in a few wells appears to be merged with the Hundred-foot, the intervening shale being absent; sometimes it carries gas.

Pine Run sand.—In wells drilled at Mateer, a gas-bearing sand was found 275 feet below the top of the Murrysville. A sand at this horizon about 20 feet thick is shown in the records of wells in other parts of the quadrangle, but only at this point is it given a name. The origin of the term is not known. It is separated from the Hundred-foot sand by shale, sandstone, or sandy shale, and lies only a few feet above a considerable thickness of red beds.

Sub-Blairsville red beds.—A conspicuous mass of red shale is shown in all the wells which go more than 1,300 feet below the Vanport limestone. The top of this red rock is usually from 300 to 350 feet below the top of the Murrysville sand, and the color extends through an average thickness of 300 feet in this region. The rocks probably constitute a part of what is known as the Catskill formation and may be of Devonian age. They are not known in outcrop and because of their considerable development in wells drilled in the vicinity of Blairsville have been called by Campbell (Latrobe folio, No. 110) the Sub-Blairsville beds. Richardson noted this mass of red rocks as occurring in wells in the Indiana quadrangle at a depth of 1,400 to 1,500 feet below the Upper Freeport coal and correlated them in a number of well records on columnar section sheet 2 in the Indiana folio, No. 102.

It will be seen by reference to the plates of well sections that the correlation lines drawn at the top and bottom of the Sub-Blairsville red beds include in a number of cases more shales and sandstones than those which the drillers noted as being red. These lines limit the zone in which red beds occur rather than mark the occurrence as actually

noted, and are the author's interpretation of the probable correlation between the sections. In the Crownover, Kerr, King, Stahl, and other wells red beds occupy the entire interval; in the Sturgeon well they are in the upper portion, and in the Robinson well they are in the lower portion of the zone, while in the Jones well no red beds are recorded. It is assumed that if particular attention had been paid to the subject when the wells were being drilled, the drillers' records of a number of the wells would have shown more red beds.

The age of the Patton shale member is known to be Pocono and these Sub-Blairsville red beds probably are Devonian, but the exact position of the boundary between Carboniferous and Devonian rocks beneath this quadrangle is not known and can not be determined by well records alone. It is probable that there is a zone of transition in which Chemung and Pocono faunas merge.

Fifth sand.—A sand known as the Fourth sand, which occurs in the midst of the Sub-Blairsville red beds in the Rural Valley quadrangle, is not recognized by drillers in this field. The Fifth sand is at the base of the red beds from 600 to 700 feet below the top of the Murrysville sand and from 1,700 to 1,900 feet below the Upper Freeport coal. According to well records it ranges in thickness from 5 to 49 feet, the average of 21 records being 21 feet. The position and correlation of the Fifth sand are shown on Pl. X.

Three wells shown on this sheet, which go below the Fifth sand, show another sand of about the same thickness 150 feet below the bottom of the red beds. In the Moore well it is 225 feet below. This was called the Fifth sand in the Graff and Henry Reefer wells.

Speechley sand.—At least three wells in the Elders Ridge quadrangle have a depth of more than 2,900 feet. These are the Nicholas Reefer (No. 93) and Samuel Graff (No. 96) wells in Plum Creek Township, and the Samuel Bracken well (No. 149) in Washington Township. At depths of 2,460, 2,495, and 2,540 feet, respectively, below the Upper Freeport coal, these wells encountered a sand in the midst of "slate and shells." In two wells it is 40 feet thick and in the third 20. This sand produces gas in some fields.

Tiona sand.—The three wells mentioned in the preceding paragraph encountered a lower sand which drillers call the Tiona. In the Graff and Reefer wells the top of the Tiona is 150 feet below the top of the Speechley sand, and in the Bracken well 100 feet below it. On the other hand, the distance from the Upper Freeport coal to the Tiona sand in the Bracken and Graff wells is 2,640 and 2,646 feet, respectively, a remarkably close accordance, while in the Nicholas Reefer well the interval is 2,610 feet. The Speechley and Tiona sands are shown on Pl. X.

The well on the Samuel Bracken farm (No. 149), near Russell Hill,

3 miles north of Shelocta, is, so far as is known to the writer, the deepest well in the Elders Ridge quadrangle. Its total depth is 3,025 feet.

DESCRIPTIONS OF GAS FIELDS.

The seven gas fields in this quadrangle are described in the order in which they occur from east to west.

Willet field.—The locality of a group of producing wells, which extends across the Indiana–Elders Ridge quadrangle line on the south branch of Plum Creek, takes its name from Willet, at the mouth of Sugarcamp Run in the Indiana quadrangle. Gas was discovered in the Kelly No. 1 well in December, 1890, and other wells were soon put down. An effort to find a northeastern extension of this producing area has been without success thus far. To the southwest, however, several good wells have been struck and the field extended to Dutch Run, in the Elders Ridge quadrangle. The Willet field is located on the Dutch Run anticline. Of the 25 wells which have been drilled between Sugarcamp Run on the northeast and the John Snyder well (No. 150) on the southwest, all but 5 or 6 are producing. The pressure is light in this field, but none of the good producing wells have been exhausted thus far. It is said that the Kelly No. 2 well (No. 161) on Plum Creek had a rock pressure of 225 pounds when the well was drilled in 1891 and a minute pressure of 125 pounds in a 5⅝-inch casing. In 1901 the rock pressure in this well had decreased to 100 pounds. All of the wells in this field have a little salt water, but not enough to hurt them. The Willet field is operated almost entirely by the Indiana County Gas Company, only two or three wells having been sunk in this region by the Peoples Natural Gas Company. The gas is piped to Indiana and Pittsburg.

The gas-producing sand in this field occurs about 1,100 feet below the Upper Freeport coal, which is the horizon of the Murrysville sand. It varies from 15 to 25 feet in thickness, and is a uniform, moderately compact, light-gray sandstone.

Plum Creek field.—There is a group of wells near the mouth of Plum Creek, a locality known as the Plum Creek field. They number less than 20, and were drilled by the Indiana County Gas Company, the Peoples Natural Gas Company, and the Philadelphia Company. Most of the drilling has been done since 1898. The wells are producing from the Murrysville sand, which is found in this field at 1,085–1,115 feet below the Upper Freeport coal. One of the Boyer wells drilled in this field in 1901 on the east side of the creek is reported to have had a rock pressure of 350 pounds in a 6¼-inch casing. The Ralston well (No. 141), at the mouth of Dutch Run, is reported by the Indiana County Gas Company to have a rock pressure of 260 pounds in a 2-inch packed tubing, with a daily capacity of 1,100,000 cubic feet.

The rock pressure in the Ralston well (No. 132), drilled by the Philadelphia Company 1 mile north of Idaho, when completed in 1899, was 140 pounds.

The Plum Creek field is located on the southern portion of the Dutch Run anticline, the westernmost wells being near the point where the axis plunges against the flank of the Roaring Run anticline as it swings to the north.

Say Farm field.—The locality of a group of wells drilled in Plum Creek Township, in the northern part of this quadrangle, is yet sufficiently segregated to be known as a separate field. It takes its name from the farm on which the first producing well was drilled, and although usually limited to the close group in the immediate vicinity, the term may be extended to include all wells between Elderton on the south and Blanco, in the Rural Valley quadrangle, on the north. The development of this field began in 1897, when a well (No. 77) was put down on the A. L. Say farm. It was completed August 23, having passed through the Murrysville and Hundred-foot sands, and obtained a strong flow of gas. The pressure at the end of the first minute was 215 pounds and the rock pressure 530 pounds. Other wells which showed good rock pressure when they came in were as follows: Alex. Clark, 360 pounds; S. R. Say, 355; W. St. Clair, 353; McPherson No. 1, 205; N. & W. Reefer, 178; Rupp & Hemphill No. 2, 175. A few wells in this field have shown very little pressure or have been dry. The largest well in the field was completed in November, 1902, on the Jacob Wingard farm (No. 88) by the Eastern Oil Company. The Murrysville, Hundred-foot, and Thirty-foot sands were dry, but at a depth of 225 feet below the top of the Hundred-foot a sand was penetrated which yielded 2,200,000 cubic feet of gas per day. This was called the Third sand by the driller, and overlies the Sub-Blairsville red beds, being at the horizon of the Pine Run sand in the Shellhammer field.

The records of 20 wells in this field show that most of the gas comes from the top of the Murrysville and lower part of the Hundred-foot sands. The average thickness of the Murrysville in these records is 78 feet, although the recorded thickness varies from 35 to 134 feet. The Hundred-foot seems to vary from 40 to 165 feet in thickness, with an average of 95. The average distance from the top of the Murrysville to the top of the Hundred-foot is 139 feet. Another name used in this field for the Murrysville is Salt sand.

The earliest wells in this field were drilled in the following order in the latter part of 1897: A. L. Say, August 23 (No. 77); J. R. Dunmire, August 30 (No. 68); Absolom Smith, September 4 (No. 66); S. R. Say, October 13 (No. 76); Sturgeon, November 24 (No. 113).

Gas wells in a new field decline more rapidly during the first year or two than in subsequent years. At the present time the decline in

this field is very slow. All the producing wells are nearly as good as they were three years ago, some showing rock pressure as high as 75 and 100 pounds.

The Say Farm field is located on the crest and upper flanks of the Roaring Run anticline, the closest group of wells, including those on the Say, Rupp & Hemphill, McPherson, and adjoining farms, being in a structural saddle on the axis. Almost all of the wells have been drilled by the Philadelphia Company, the only other producers engaged in this field being the Peoples Natural Gas Company.

Girty field.—This field extends from Shady Plain, Kiskiminitas Township, northward to the head of Sugar Run, Plum Creek Township, and westward to within a mile of Cochran Mills. It contains about 45 wells, most of which have been drilled by the Philadelphia Company and the Peoples Natural Gas Company since 1895. The Murrysville or Salt sand and the Hundred-foot sand are the gas producers. The records of all wells give an average thickness of 63 feet for the Murrysville sand, and the distance from the top of it to the top of the Hundred-foot sand is 144 feet. In some records the Hundred-foot is recorded as being 25 to 40 feet thick, while in others from 100 to 125 feet. The Salsgiver well (No. 178), which was one of the first drilled in this field, had a rock pressure of 325 pounds. A majority of the wells are good producers after several years of activity. The field is located on the broad double crest of the Roaring Run anticline.

Roaring Run field.—The territory included in this field extends from Shady Plain southwestward along the valley of Roaring Run. The wells in that portion of the field which lies in the Elders Ridge quadrangle are about 20 in number and are for the most part close to the axis of the Roaring Run anticline. On the ridge east of Roaring Run a well was completed on the C. A. Wright farm (No. 254) September 20, 1894, the first one drilled in this portion of the field. The first well drilled at Equitable was the Lewis Kunkle No. 1 (No. 246), which was completed December 12, 1894. Before the following summer 6 wells had been drilled on the Kunkle farm and three on the Hilty Brothers farm, a short distance down the run. The wells in this field produce from the Murrysville and Hundred-foot sands, the larger amount coming from the latter. The records at hand show nothing concerning production except that rock pressure in the Chambers No. 1 (No. 223), drilled by the Carnegie Natural Gas Company, was 325 pounds, and that the casing of the Hilty Brothers No. 1, just beyond the boundary of this quadrangle, broke with 510 pounds pressure. A large number of the wells in this field were drilled by the Equitable Company and sold by them to the Philadelphia Company in 1899. In 1902 the Philadelphia Company sold all the wells in the field to the American Natural Gas Company, which is utilizing them to-day.

Shellhammer field.—The gas field in the vicinity of Mateer, Burrell Township, on the south side of Crooked Creek, takes its name from the farm on which the first producing well in the field was drilled. It is composed of thirty or more wells, which have been drilled by the Apollo Gas Company, Pittsburg Plate Glass Company, and Philadelphia Company. The first well in the field was completed on the Jacob Shellhammer farm early in 1899. Two wells were drilled on the Shellhammer farm (Nos. 194 and 195) by the Apollo Gas Company in the summer of 1894, and large flows of gas were obtained. The well which came in on July 2 had such a strong pressure of gas from the Hundred-foot sand that the tools were held off the bottom. A gauge showed 400 pounds in forty-five seconds. The well completed September 1 of the same year had a pressure of 200 pounds in thirty seconds and rock pressure of 280 pounds. Three wells drilled on the David Riffer farm (Nos. 188, 189, and 190) by the Philadelphia Company in the summer of 1894 also obtained strong flows of gas in the Hundred-foot sand. These wells showed minute pressures of 320, 225, and 115 pounds, and rock pressures of 340, 253, and 120 pounds, respectively. The Riffer wells were abandoned after six years of productiveness.

The Apollo Gas Company has two small gas-pumping stations in this field which have a daily capacity of about 1,500,000 cubic feet each. The stations draw from 14 wells.

The Shellhammer field seems to be located on a low anticlinal fold which crosses Crooked Creek a short distance below Cochran Mills, and which was called the Apollo anticline by Platt. Gas is found largely in the Hundred-foot and Pine Run sands.

Rockville field.—The locality of the group of gas wells on the Greendale anticline, in the northwest corner of the quadrangle, is known as the Rockville field. Most of the drilling here has been done by the Philadelphia Company and the Pittsburg Plate Glass Company. The first well in the field was drilled on the Anthony Kealor farm (No. 22), a half mile north of Rockville, by the Philadelphia Company in December, 1893. Gas was found in the Hundred-foot and Fifth sands, and flowed with a minute pressure of 32 pounds. The well developed a rock pressure, however, of 430 pounds. A well on the Savander Schall farm (No. 28), at Rockville, drilled by the same company in 1894, came in with a minute pressure of 365 pounds, gas coming from the Hundred-foot sand, while the Crim No. 1 (No. 27), located only a few hundred yards from the Schall well and completed the same year, found gas in the Fifth sand with a minute pressure of 130 pounds and a 30-minute pressure of 385 pounds.

Jackson Heffelfinger No. 1 well (No. 42), drilled by the Pittsburg Plate Glass Company three-fourths of a mile west of Rockville, went to the Fifth sand and got a 70-pound minute pressure and rock pressure

of 290 pounds. In comparison it is interesting to note that the Isaac Heilman well, 2 miles northwest of Rockville, yielded gas from the Fifth sand with a minute pressure of only 43 pounds, but the rock pressure went up to 345 pounds. The gas in this field comes from the Murrysville, the Hundred-foot, and the Fifth sands and is piped to Pittsburg and Ford City.

Miscellaneous wells.—There are a number of wells in the quadrangle which can not properly be included in any of these fields. A group on the bend of Crooked Creek 3 miles below Cochran Mills was drilled largely by the Carnegie Natural Gas Company. Many of these wells are producing.

A well (No. 61) back of the schoolhouse at Brick Church, drilled in 1892, although located close to the axis of the Apollo syncline, had a minute pressure at the outset of 109 pounds and a rock pressure of 351 pounds in a 6¼-inch casing. The productiveness of this well diminished rapidly after three or four months, however, and is now very small. Also a well on the Hugh Blakley farm (No. 238), a mile north of West Lebanon, which was located on the axis of the Elders Ridge syncline, obtained a strong flow of gas. On the other hand, a well drilled on the same axis at the creamery on the Smith farm (No. 239), near Elders Ridge, yielded a very little gas, which was more than could be expected from its location. A second well (No. 240) drilled to the Fifth sand on the same farm in 1903 was absolutely "dry."[a]

A well at Salina (No. 257) and another at the mouth of Blacklegs Creek (No. 259), in the Elders Ridge syncline, have yielded enough gas to light a few burners only, while a well between these two at the mouth of Long Run (No. 258) was unproductive. In a few cases deep holes sunk near the crest of an anticline have been very light producers or unproductive. Among these are the Lohr No. 2 (No. 156), drilled by the Indiana County Gas Company on the Dutch Run anticline north of Advance; the Ramsey well (No. 148), drilled by the Peoples Natural Gas Company on Dutch Run between the Willet and Plum Creek fields; and a well a half mile west of Kent (No. 262) on the Jacksonville anticline, drilled by the Saltsburg Gas Company.

Possible extension of fields.—The delineation of the geologic structure on the economic geology map suggests the directions in which there is the most chance of further drilling being remunerative. Territory which has not yet been thoroughly tested and which promises to be gas bearing is (1) the narrow strip between Dutch Run and Russell Hill extending from the Willet to the Plum Creek field, and (2) along the crest of the Jacksonville anticline from Lewisville to Watt Hill and the head of Reeds Run.

[a] During the prosecution of field work in 1902, the writer was on the Smith farm, and, being informed that a second well for gas was contemplated, advised strongly against further drilling, as the theory of the accumulation of gas pointed against the probability of there being any quantity of it in the immediate vicinity.

DISPOSAL OF GAS.

Gas produced in the fields of this quadrangle is carried by pipe lines to more or less distant markets. The Indiana County Gas Company pipes gas from the Willet and Plum Creek fields to the town of Indiana.

The Philadelphia Company's main trunk line from Pittsburg to the Armstrong County field is a 20-inch pipe line which crosses Crooked Creek on the Banks farm at the big bend, and thence running northward ends on the Wray farm at Rockville in Kittanning Township. Branches from this point to the Say farm and other fields are 8 and 10 inch lines.

The Peoples Natural Gas Company's trunk pipe line from Pittsburg to this part of Armstrong County sends tributaries to nearly all productive portions of the northern part of the quadrangle. This company has a pump station on Crooked Creek below Girty which is supplied by 58 of its own wells and 5 belonging to the Indiana County Gas Company. This string of wells is held in reserve much of the time, but when in use they yield between 7,000,000 and 8,000,000 cubic feet of gas per day. The gas is consumed in Pittsburg and surrounding towns for domestic and manufacturing purposes.

A 10-inch branch of the Carnegie Natural Gas Company's 16-inch main trunk line from Pittsburg extends to the vicinity of Cochran Mills. The pump station, located at Bagdad on Kiskiminitas River, is now handling about 5,000,000 cubic feet of gas daily from forty-five producing wells. The gas produced by this company is consumed in the Edgar Thomson, Homestead, and Duquesne steel works.

The Pittsburg Plate Glass Company, largely interested in the Rockville field, pipes its gas to its own plant at Ford City. The gas is taken through an 8-inch line to the pump station at Copes Mills. The main supply of this company is brought from north of Cowanshannock Creek.

A branch from the Apollo Gas Company's main trunk line, which extends from Vandergrift Mills, Vandergrift, Pa., northward through Armstrong County, runs from Dime post-office to the Shellhammer field at Mateer, where the company has two pump stations. With the exception of the amount used for domestic consumption at Vandergrift, the company's entire supply of gas is furnished for manufacturing purposes to the American Sheet and Tin Plate Company at Vandergrift, Hyde Park, and Leechburg.

Many dwellings in the northern part of the quadrangle are lighted and heated by natural gas. At some farmhouses not only is gas burned in the range and fireplaces but it is used for heating the brick oven, and burned as a torch in the yard all night (Pl. XII, *A*).

A. YARD GAS TORCH.

B. STONEWARE MADE FROM KITTANNING CLAY AT GIRTY.

LIST OF DEEP WELLS.

Deep wells in Elders Ridge quadrangle.

No. on map.	Name of well.	Owner.	Approximate elevation above sea level.	Depth of well.
1	Heilman, Isaac	Philadelphia Co	1,150	1,907
2	King, George	do	1,090	.....
3	McClune, Samuel	do	1,020	.....
4	Campbell, Daniel	do	1,020	.....
5	.....	.....	1,000	.....
6	Robinson, No. 2	Pittsburg Plate Glass Co	1,100	1,939
7	Robb, T. K	do	1,180	1,945
8	Walker	do	1,020	.....
9	Crownover, J. T	do	1,120	1,970
10	Kerr, Jacob	.....	880	.....
11	Robinson, No. 1	Pittsburg Plate Glass Co	1,050	1,891
12	Jones, Thomas	do	1,100	1,932
13	Heilman, Louis	do	1,030	1,829
14	Briney	Philadelphia Co	1,100	2,002
15	Nolder, Martin	do	1,290	1,975
16	Campbell, William	do	1,300	2,016
17	Cravener, Andrew	Pittsburg Plate Glass Co	1,250	1,618
18	Schaeffer, Salina	do	1,370	1,360
19	Blaney, J. A	Philadelphia Co	1,140	.....
20	Boarts, Ed	do	1,290	1,960
21	Schall, L. H	do	1,160	1,858
22	Kealor, Anthony	do	1,120	1,770
23	McCullough	do	1,160	1,420
24	Heffelfinger, J. F., No. 3	Pittsburg Plate Glass Co	1,230	1,871
25	Louden, Matthew	Philadelphia Co	1,200	1,899
26	Wilcox, John	.....	1,200	.....
27	Crim, J. R., No. 1	Philadelphia Co	1,190	1,894
28	Schall, Savander	do	1,050	1,315
29	Schall, G. A	do	1,040	1,324
30	Heilman, Henry	do	1,175	1,925
31	Heilman, Rueben	do	1,200	2,005
32	Crim, J. R., No. 2	do	1,250	1,987
33	Hankey, R. L., No. 1	.....	1,150	.....
34	Heffelfinger, G. W.?	Philadelphia Co	1,080	1,905
35	Schall, L. & S	Pittsburg Plate Glass Co	1,250	1,468
36	Hankey, Ben, No. 1	do	1,325	1,495
37	Hankey	do	1,280	.....
38	Hankey, Tom, No. 2	do	1,300	1,665

Deep wells in Elders Ridge quadrangle—Continued.

No. on map.	Name of well.	Owner.	Approximate elevation above sea level.	Depth of well.
39	Hankey, Tom, No. 1	Pittsburg Plate Glass Co	1,200	1,406
40	Hankey, R. L., No. 2		1,290	
41	Heffelfinger, Jackson, No. 2	Pittsburg Plate Glass Co	1,300	1,480
42	Heffelfinger, Jackson, No. 1	do	1,340	2,060
43	Heffelfinger, Jackson, No. 3	do	1,180	1,871
44	Waltonbaugh, Isaac	Philadelphia Co	1,170	1,835
45	Crownover	Pittsburg Plate Glass Co	1,030	1,095
46	Spangs, Oliver		1,190	
47	Altman, Amos	Carnegie Natural Gas Co. ?	1,130	
48	Altman, Sarah	Pittsburg Plate Glass Co	1,110	
49	Spang, Isaiah	Philadelphia Co	1,100	1,388
50	Riggle, Mary	Carnegie Natural Gas Co	1,060	1,765
51	Riggle, Thomas	do	1,050	1,865
52	Robb, Jacob	do	880	1,201
53	Wingard	do	960	
54	Myers, No. 1	Pittsburg Plate Glass Co	990	1,318
55	McConnell heirs, No. 2	Carnegie Natural Gas Co	850	1,206
56	Myers, No. 2	Pittsburg Plate Glass Co	850	1,187
57	McConnell heirs, No. 1	Carnegie Natural Gas Co	960	1,420
58	Nell, John	do	1,000	
59	Slease, George	Philadelphia Co.?	1,060	
60	Hankey, William	do	1,150	2,819
61	King, H. A	Home Co	1,195	1,528
62	Schaeffer, E. E	Conemaugh Gas Co	1,060	
63	Davis, George	Philadelphia Co	910	
64	McKee, Jos., No. 1	do	980	
65	McKee, Jos., No. 2	do	1,050	
66	Smith, Absalom	do	1,150	1,281
67	Young, Peter	do	1,050	
68	Dunmire, J. R	do	1,160	1,858
69	Cessna, Adam	Peoples Natural Gas Co	1,220	1,220
70	Elgin, H. H	do	1,470	1,811
71	St. Clair, William	Philadelphia Co	1,260	1,480
72	Ormond, John, No. 2	Peoples Natural Gas Co	1,380	1,680
73	Rupp & Hemphill, No. 1	Philadelphia Co	1,410	1,680
74	Rupp & Hemphill, No. 2	do	1,225	1,550
75	Rupp & Hemphill, No. 3	do	1,220	1,551
76	Say, S. R	do	1,310	1,386
77	Say, A. L	do	1,270	1,565

Deep wells in Elders Ridge quadrangle—Continued.

No. on map.	Name of well.	Owner.	Approximate elevation above sea level.	Depth of well.
78	St. Clair	Pittsburg Plate Glass Co	1,265	2,006
79	St. Clair, Milton	Peoples Natural Gas Co	1,350	1,750
80	Crawford	Home Co	1,080	.....
81	St. Clair	do	1,140	.....
82	Blaney, J. A	Philadelphia Co	1,250	.....
83	Hemphill, Archibald	do	1,200	.....
84	Shetler, H	Eastern Oil Co	1,240	1,515
85	Boyer, T. & F	do	1,200	.....
86	Gibson, L. C		1,180	.....
87	Smail, George	Peoples Natural Gas Co	1,130	1,870
88	Wingard, Jacob	Eastern Oil Co	1,430	1,620
89	McIntyre, Ed	Peoples Natural Gas Co	1,300	2,003
90	Rearick, Alex	Philadelphia Co	1,170	1,893
91	Reefer, N. & W	do	1,100	1,211
92	Chriss, Nicolas	Peoples Natural Gas Co	1,090	.....
93	Reefer, Nicolas	Philadelphia Co	1,270	2,965
94	Reefer, Jacob	do	1,100	1,881
95	Reefer, Henry	do	1,160	2,169
96	Graff, Samuel	do	1,075	2,943
97	Bier, George	Peoples Natural Gas Co	1,280	2,050
98	Hotham, William	do	1,210	1,515
99	Nelson, Mrs., No. 1	do	1,250	1,504
100	Nelson, Mrs., No. 2	do	1,170	1,510
101	Cribbs, Michael	do	1,120	1,505
102	Kaufman, Nicholas	do	1,310	1,635
103	Dick, P. & D	Philadelphia Co	1,260	1,580
104	Gibson, L. C., No. 2	Peoples Natural Gas Co	1,260	.....
105	Gibson, L. C., No. 3	do	1,260	.....
106	Yount, Andrew, No. 2	Philadelphia Co	1,260	1,680
107	McPherson, No. 2	do	1,280	2,126
108	McPherson, No. 1	do	1,340	1,653
109	Gibson, L. C., No. 1	Peoples Natural Gas Co	1,210	.....
110	Clark, Alex., No. 1	Philadelphia Co	1,280	1,665
111	Clark, Alex., No. 2		1,220	.....
112	Gibson, L. C., No. 1	Pittsburg Plate Glass Co	1,250	1,595
113	Sturgeon, W. B	Philadelphia Co	1,320	2,101
114	Yount, Andrew, No. 1	do	1,425	1,770
115	Yount, William	Peoples Natural Gas Co	1,340	1,660
116	Eyler, No. 1	do	1,220	1,515

Deep wells in Elders Ridge quadrangle—Continued.

No. on map.	Name of well.	Owner.	Approximate elevation above sea level.	Depth of well.
117	Rosborough	Peoples Natural Gas Co	1,180	2,405
118	McCullough, W. D	do	1,180	1,450
119	Strickland, C. D	do	1,300	1,640
120	Turner	Philadelphia Co	1,170	1,800
121	McCullough, Eliz	do	1,270	1,814
122	Peterman	Peoples Natural Gas Co	1,260	1,265
123	Rankin, Harvey	Philadelphia Co	1,400	.....
124	Frick, Simon, No. 2	Peoples Natural Gas Co	1,390	1,380
125	Rowland, John F	do	1,120	1,170
126	Smetzer, A	do	1,110	1,100
127	Smith heirs	do	1,080	1,475
128	Keener, R. M	do	1,210	1,972
129	Frick, Simon, No. 1	do	1,260	1,325
130	Walker, Eliz., No. 2	do	1,080	1,435
131	Harmon, A. C	do	1,040	1,435
132	Ralston, W. M	Philadelphia Co	1,090	1,765
133	Clark, William, No. 1	Peoples Natural Gas Co	1,110	1,520
134	Kimmel, J. B., No. 1	do	1,035	1,460
135	Clark, William, No. 2	do	1,000	.....
136	McCracken	.....	980	.....
137	Herron, Mrs. M. T	Peoples Natural Gas Co	990	.....
138	Frailey heirs	do	1,230	1,665
139	Herron, John C	do	1,050	1,175
140	Kimmel, J. B., No. 2	do	990	1,390
141	Ralston, No. 1	Indiana County Gas Co	1,050	.....
142	Clark, H. A	do	1,100	1,165
143	Beatty heirs	do	1,170	1,220
144	Boyer, No. 1	do	1,090	1,120
145	Boyer, No. 2	do	1,170	1,220
146	Croyle, Ralph	.....	1,190	.....
147	Gristmill well, near Gastown	.....	995	.....
148	Ramsey	Peoples Natural Gas Co	1,050	1,825
149	Bracken, Samuel	do	1,260	3,025
150	Snyder, John	Indiana County Gas Co	1,340	1,620
151	Peterman, No. 1	do	1,360	1,360
152	Miller, B. M., No. 2	do	1,120	1,155
153	Miller, B. M., No. 1	do	1,130	1,187
154	Miller, George	do	1,140	1,200
155	Speedy heirs	do	1,235	1,245

Deep wells in Elders Ridge quadrangle—Continued.

No. on map.	Name of well.	Owner.	Approximate elevation above sea level.	Depth of well.
156	Lohr, No. 2	Indiana County Gas Co	1,270	1,260
157	Lohr, No. 1	do	1,100	.....
158	Altemus, T. J	do	1,040	.....
159	Repine	do	1,035	1,100
160	Kelly, No. 5	do	1,060	.....
161	Kelly, No. 2	do	1,040	.....
162	Kelly, No. 3	do	1,050	.....
163	Kelly, No. 6	do	1,100	.....
164	.....	.....	960	.....
165	Kinnard (?)	.....	865	.....
166	McKee, F. T	Philadelphia Co	885	2,311
167	Farster, D	do	1,090	1,859
168	Miller, Addison	do	1,250	1,296
169	Fiscus, James	do	1,290	.....
170	Davis, Jackson	do	1,200	1,447
171	Deshong, James, No. 2	do	1,300	1,260
172	Deshong, James, No. 1	do	1,330	1,325
173	Flickinger, J. F., No. 1	do	1,130	1,860
174	Flickinger, J. F., No. 2	do	1,325	1,735
175	Kinnard, B. F	.....	1,030	.....
176	Rupert, Riley	Peoples Natural Gas Co	1,260	1,450
177	Grimm, D. W	do	1,130	1,315
178	Salsgiver	Philadelphia Co	1,020	1,280
179	McCormick, Mary	do	1,120	1,740
180	Christy	Peoples Natural Gas Co	1,020	1,280
181	Ambrose	do	990	.....
182	Barr, James T	do	1,040	1,225
183	Henderson, Thomas	do	1,220	1,650
184	Rayburn, Calvin	do	1,000	.....
185	McKee	Equitable Gas Co	910	990
186	do	do	910	.....
187	.....	.....	930	.....
188	Riffer, David, No. 1	Philadelphia Co	1,040	1,421
189	Riffer, David, No. 2	do	1,100	1,452
190	Riffer, David, No. 3	do	1,130	1,506
191	Riggles	.....	1,000	.....
192	Rearick	.....	1,050	.....
193	do	.....	1,060	.....
194	Shellhammer, Daniel	Apollo Gas Co	1,080	1,444?

Deep wells in Elders Ridge quadrangle—Continued.

No. on map.	Name of well.	Owner.	Approximate elevation above sea level.	Depth of well.
195	Shellhammer, Daniel	Apollo Gas Co	1,090	1,464?
196	Fakman (?)	Pittsburg Plate Glass Co	1,200	.....
197	Riggle, P. T	.....	1,230	.....
198	.....do	.....	1,220	.....
199	Porter	Peoples Natural Gas Co	1,150	1,515
200	.....do	.....do	1,090	.....
201	Riggle	.....	1,150	.....
202	Clark, J. W., No. 2	Apollo Gas Co	1,050	1,523
203	Clark, J. W., No. 1	.....do	1,070	1,536
204	Ramaley	.....do	1,100	1,572
205	Hauser	.....	1,030	.....
206	Klingensmith, No. 1	Apollo Gas Co	1,060	.....
207	Altman, Foster	.....	1,070	.....
208	Klingensmith, No. 2	Apollo Gas Co	1,150	.....
209	Waltonbaugh, Mrs	.....do	1,000	1,362
210	Knappenberger	.....do	980	1,372
211	Smith	.....	1,100	.....
212	.....do	.....	1,170	.....
213	.....do	.....	1,300	.....
214	Klingensmith	Apollo Gas Co	1,250	.....
215	Miller, Emma	.....	1,190	.....
216	.....do	.....	1,190	.....
217	Marshall	.....	1,200	.....
218	.....do	.....	1,220	.....
219	.....do	.....	1,240	.....
220	Dible, Samuel	Carnegie Natural Gas Co	1,405	2,180
221	Lunderstead	.....	1,370	.....
222	Cochran, George	.....	1,400	.....
223	Chambers	Carnegie Natural Gas Co	1,390	1,410
224	Howell	.....	1,290	.....
225	Heasley	Peoples Natural Gas Co	1,350	1,524
226	Dice, T. M., No. 1	Conemaugh Gas Co	1,180	1,500?
227	Dice, T. M., No. 2	.....do	1,080	.....
228	Pierce	.....	920	.....
229	Kirkland, J. G., No. 1	.....	1,300	.....
230	Kirkland, J. G., No. 2	.....	1,070	.....
231	Matson, Amanda	.....	1,120	.....
232	Miller, Mary	Peoples Natural Gas Co	1,070	.....
233	Painter (?)	.....	1,200	.....

Deep wells in Elders Ridge quadrangle—Continued.

No. on map.	Name of well.	Owner.	Approximate elevation above sea level.	Depth of well.
234	King, W. G., No. 2	Ford City Gas Co	950	.....
235	King, W. G., No. 1	.....do	990	1,620
236	Dever, Joseph	.....	1,040	.....
237	Orr, W. C	Home Co	1,280	.....
238	Blakley, Hugh	.....	1,085	2,322
239	Smith Bros	Peoples Natural Gas Co	1,160	2,707
240	Smith heirs	Home Co	1,280	2,078
241	Nepshell, George	Equitable Gas Co	1,490	.....
242	.....	.....	1,150	.....
243	Scott (?)	.....	1,130	.....
244	Amment (?)	.....	1,080	.....
245	Bowser (?)	.....	1,080	.....
246	Kunkle, Lewis, No. 1	Equitable Gas Co	1,080	1,236
247	Kunkle, Lewis, No. 6	.....do	1,090	.....
248	Kunkle, Lewis, No. 2	.....do	1,080	1,245
249	Martin, W. P	.....do	1,220	.....
250	Martin, Daniel (?)	.....	1,250	.....
251	Deemer, Philip	.....	1,240	.....
252	Fass, Andrew	Apollo Gas Co	1,350	.....
253	Wright, C. A., No. 3	Equitable Gas Co	1,400	1,528
254	Wright, C. A., No. 1	.....do	1,280	1,593
255	Bier, Herman	.....do	1,400	1,602
256	Guthrie, William	.....	1,250	.....
257	Salina	Kier Fire Brick Co	810	.....
258	Avonmore	Home Co	840	.....
259	Sheet Steel Mill	Apollo Gas Co	860	2,172
260	Dunlop	Equitable Gas Co	1,300	1,545
261	Stahl, Geo. W	Conemaugh Gas Co	1,420	2,018
262	Jacksonville	Saltsburg Gas Co	1,170	1,930
263	Uncafer, Augustus	Conemaugh Gas Co	1,360	1,992

OIL.

A trace of oil has been detected at various horizons in a number of wells drilled in this quadrangle, but only one well is producing and that in very small quantity. It is located on the St. Clair farm (No. 81), a quarter of a mile east of Whitesburg, on the axis of the Apollo syncline, and is said to spray one barrel of oil every two days. The gas has a minute pressure of 2 pounds, and a rock pressure of 70 pounds.

LIMESTONE.

There are several thin beds of limestone and two heavy ones in the formations exposed in the area under discussion. It happens that the lowest rock in the geologic column here exposed is the Vanport limestone, which outcrops at two points on Crooked Creek, and the highest is the Benwood limestone, which crowns the hills at Elders Ridge.

The Vanport limestone occurs below the lower Kittanning coal and fire clay, from which it is separated by sandstone. The limestone is usually compact and brittle, and has a grayish color; it is of good quality through its entire thickness, which is from 8 to 10 feet on Crooked Creek. As seen near the "Loop" it is very fossiliferous, containing a marine fauna consisting principally of crinoids, brachiopods, and lamellibranchs. Throughout western Pennsylvania this limestone universally contains less than 2 per cent of magnesium carbonate. The insoluble siliceous matter is likewise low, while the proportion of calcium carbonate is high. The stone has been used for the manufacture of Portland cement. For this cement a limestone must carry less than 5 per cent of magnesium carbonate and at least 75 per cent of calcium carbonate, and in an ideal cement limestone the proportion of silica to alumina plus iron should be 5:2. However, as this ratio can usually be obtained by mixing with other raw materials, it is not necessary that the stone should possess such a silica-alumina ratio. This limestone also makes excellent ballast, road metal, flux, and fertilizer.

An analysis of this stone, from Girty, made by Mr. McCreath, shows the following chemical composition:[a]

Analysis of Vanport limestone at Girty.

	Per cent.
Insoluble residue	2.100
Calcium carbonate	94.185
Magnesium carbonate	1.483
Alumina and ferric oxide	2.089
Phosphorus	.031

The Johnstown limestone, which lies under the Upper Kittanning coal and is seen a few feet above the creek at Cochran Mills, contains high percentages of magnesia, silica, and other impurities and is wholly unsuited for Portland cement, although it will make natural cement. A peculiarity of this limestone is its great variation in the amount of calcium carbonate, from 36 to 92 per cent, and of magnesium carbonate, from 1 to 30 per cent. A specimen taken from the M. Davis property at Cochran Mills was analyzed by Mr. McCreath with the following results:[b]

[a] McCreath, A. S., Second Geol. Survey of Pennsylvania, Rept. H5, p. 64.
[b] McCreath, A. S., Second Geol. Survey of Pennsylvania, Rept. H5, p. 67.

Analysis of Johnstown limestone at Cochran Mills.

	Per cent.
Insoluble residue	23.840
Calcium carbonate	53.750
Magnesium carbonate	9.989
Ferric oxide and alumina	7.730
Phosphorus	.131

This stratum, as seen on Crooked Creek, is not more than 3 feet thick, and is from 2 to 8 feet below the Upper Kittanning coal.

The Lower Freeport limestone is a thin bed, variable both in occurrence and in amount of impurities, and can generally be little depended on for economic purposes. It was not noted in this quadrangle. It is reported at many points in southwestern Pennsylvania, but probably is not persistent for long distances, and is not known to have at any place a greater thickness than 5 feet.

The Upper Freeport limestone is occasionally of workable thickness, and usually of considerable purity. It underlies the Upper Freeport coal, and throughout the Allegheny Valley is usually less than 6 feet thick. The majority of the analyses made by the Second Survey show a small percentage of magnesia with about the right proportions of iron, alumina, and silica to qualify it for a good flux or Portland cement. Two analyses are given below. One specimen was from Rev. S. Brown's quarry, 1½ miles southwest of Willet at the mouth of Sugarcamp Run and therefore in the valley of the South Branch of Plum Creek, less than a mile east of the boundary of the Elders Ridge quadrangle. The other was from Hazlett's quarry 2 miles south of Jacksonville. In both cases the limestone was compact, brittle, and bluish gray, with subconchoidal fracture.

Analyses of Upper Freeport limestone.

	Plum Creek.	Jackson-ville.
	Per cent.	*Per cent.*
Insoluble residue	6.021	5.430
Calcium carbonate	84.125	89.821
Magnesium carbonate	5.198	1.801
Ferric oxide and alumina	3.220	1.700
Sulphur	.073	.133
Phosphorus	.014	.027

The Pittsburg limestone underlies the Pittsburg coal at an interval of 10 to 15 feet and is several feet thick. It is confined to the southern half of the quadrangle. This stone is burned for lime on a number of farms and is used for fertilizer. It is quarried for this purpose in a small way on the Simon Townsend farm east of Olivet. It seems

to be of a moderate degree of purity, as shown by the following analysis made from a sample taken at A. H. Fulton's quarry, West Lebanon:

Analysis of Pittsburg limestone at West Lebanon.

	Per cent.
Insoluble residue	10.327
Calcium carbonate	82.768
Magnesium carbonate	2.875
Ferric oxide and alumina	2.830
Sulphur	.156
Phosphorus	.011

The limestone at this point is generally compact and brittle, with irregular fracture and bluish-gray color. It is seamed with bluish-black limestone.

The Sewickley limestone in general is obscure. According to Platt it is exposed in the cliffs on the north side of Kiskiminitas River at Hicksville, and is about 6 feet thick. It is about 85 feet above the Pittsburg coal and a few feet below the Sewickley coal. The rock is seen in the ravine below Mr. Ewing's house near Olivet, and has been quarried there. The only available analysis of the limestone in this region is of a sample from Robert Smith's quarry, 2 miles northeast of Blairsville:

Analysis of Sewickley limestone, Indiana County.

	Per cent.
Insoluble residue	12.160
Calcium carbonate	79.821
Magnesium carbonate	3.601
Ferric oxide and alumina	3.020
Sulphur	.117
Phosphorus	.018

The Benwood limestone, which occurs about 80 feet above the Sewickley coal in this quadrangle, caps a number of rounded knobs near Elders Ridge. It consists of several layers separated by variable intervals of shale, the whole deposit being not less than 25 feet thick. The limestone strews the surface where it outcrops with small pieces of grayish nonfossiliferous rock. Calcined, it makes strong lime, excellent for fertilizing purposes. The rock can be quarried at little expense, no stripping being required. Nothing is known of its chemical composition in this region.

Further information concerning the limestones of western Pennsylvania is contained in Bulletin No. 249, by Mr. F. G. Clapp, to whom the author is indebted for some of the above statements on this subject.

SANDSTONE.

Sandstone suitable for building purposes occurs in several localities within the Elders Ridge quadrangle. The principal beds are the Kittanning, Freeport, and Butler of the Allegheny formation, and the

Mahoning, Saltsburg, Morgantown, and Connellsville of the Conemaugh formation. These sandstones are mostly gray and buff and vary from soft and loose textured to hard and compact rocks. But few stone buildings have been constructed within this area, so the durability of the dressed stone is not known. The Kittanning, Freeport, and Butler sandstones are conspicuous in the bluffs on Crooked Creek below South Bend. The Kittanning sandstone was quarried at Girty many years ago for flagstones and tombstones. It separates easily into large smooth layers from 1 to 5 inches thick. The Mahoning is particularly heavy at Jacksonville, and forms the top of the bluff at Cochran Mills. The Saltsburg is well developed in the vicinity of Lewisville and Salina and on the ridge between Long Run and Roaring Run. A heavy sandstone which seems to be at the horizon of the Morgantown is conspicuous on the hilltops in the extreme northeastern corner of the quadrangle, and in the vicinity of West Lebanon.

Fifty feet below the Pittsburg coal a fairly heavy sandstone is often seen in this quadrangle. This is at the horizon of the Connellsville, and is the highest sandstone in the area except the Pittsburg, which is not strongly developed here.

CLAYS AND SHALES.

FIRE CLAY.

Two beds of fire clay in the Allegheny formation are known to be of some value. They are the Upper Freeport and Lower Kittanning clays. The first of these lies a few feet below the Upper Freeport coal and is known as the Bolivar clay. The type locality is Bolivar, on the Conemaugh River, where the clay occurs from 10 to 20 feet below the Upper Freeport coal and is worked extensively. This clay is mined at Salina on the Kiskiminitas River by the Kier Fire Brick Company. The following statement regarding the industry at Salina is taken from the Annual Report of the Pennsylvania State College for 1897, with corrections to date.

The mine and works of the Kier Fire Brick Company are located at Salina, on the West Pennsylvania Railroad, on the south side of Kiskiminitas River. They are among the oldest in the State, having been established in 1845, nearly sixty years ago. The Pittsburg office of the company is in the Stevenson Building. The company manufactures high-grade fire brick. It has 16 kilns and a daily capacity of 30,000 brick, employing 100 men and boys at the works. Pittsburg is the chief market, but shipments are made to Cleveland, the Boston Navy-Yard, and other points.

The clay used is taken from the company's own mine at the works. It is from the same geologic horizon as the Bolivar clay. The dip of the strata is to the eastward, and the drift from which the clay is

taken runs down the first hundred feet at an angle of about 15°, then changes to a more nearly horizontal position. The mine now extends probably lower than the bed of the river, and it is necessary to pump out the water. As the main heading follows the dip of the rock and the rooms branch off at a slight upgrade, the pumping can all be done from one point, the end of the main heading, and the rooms are all comparatively dry.

The clay varies from 6 to 13 feet in thickness, including both the hard flint clay and the soft plastic clay. The variation in the thickness of the flint clay is even more marked than that of the entire bed, varying in some places from a thickness of 12 or 13 feet to 2 or 3 in the same room. In some places it lies underneath the soft clay and in some places on top. The flint clay is of good quality, in most places quite clean, but in some spots it contains iron-ore balls in considerable numbers. As the ore balls are generally black, or nearly black, and much heavier than the clay, they are readily detected and picked from the clay by hand.

An average of five analyses of the clay at Salina[a] is as follows:

Average analysis of Bolivar fire clay at Salina.

	Per cent.
Silica	51.148
Alumina	31.216
Protoxide of iron	1.768
Titanic acid	1.558
Lime	.524
Magnesia	.323
Carbonic acid	.511
Alkalies	1.073
Water	10.815
Total	98.936

STONEWARE CLAY.

On Crooked Creek, just above Girty, the geologic section is as follows:

Section at Girty.

	Feet.
Sandstone, used for flagstones	25
Shale and clay	1
Lower Kittanning coal	2½
Clay, impure	4
Potter's clay	4
Shales, ferruginous	25
Vanport limestone	7
Crooked Creek	
	68½

[a] Second Geol. Survey of Pennsylvania, Rept. H5, p. 14.

The clay, which occurs a few feet below the Lower Kittanning coal, is white, of fairly good quality, and from 3 to 5 feet thick. Judging by the quality of the articles made from it, this is properly a stoneware clay. Apparently it exists in some abundance and can be raised at little cost. The present method is stripping where the bed is from 2 to 4 feet below the surface. The McNees & George pottery at Girty, which has been conducted in a small way for twenty-five years, uses this clay, taking its supply from the south bank of Crooked Creek, a mile above Girty, on the W. A. Coleman farm. The industry can not be greatly enlarged, because there is no railroad at this point. The stoneware articles made at this pottery are crocks, jugs, and pump tile (Pl. XII, *B*), all of which are much esteemed in the neighborhood.

SHALE.

Fine-textured and homogeneous deposits of shale are of widespread occurrence in the Conemaugh formation, and outcrop over a large part of the area under discussion. These shales are not utilized, but they seem to offer a field worthy of investigation. Homogeneous deposits of fine-textured, moderately fusible, and fairly plastic clay shales are available, not only for the manufacture of building brick, but for making paving brick, and many other uses to which clay is applied. In connection with limestone, suitable deposits of shale are a possible source of raw material for the manufacture of Portland cement.

WATER.

The drainage system extends to all parts of the quadrangle, so that running water can be found within a short distance of any point. The largest stream is Kiskiminitas River, which has a width of about 500 feet but is very shallow at many points. The other waterways are classed as creeks and runs.

This quadrangle is distinctly a rural district, devoted to agriculture, and, as is usual in such cases, the supply of water is drawn almost entirely from shallow wells and springs. It may be stated that in general springs are numerous, and water may be obtained at almost any point by sinking a well from 10 to 30 feet below the surface. Water troughs are located commonly at the roadside springs.

Among the rocks which are known as good water bearers are the Mahoning sandstone, which lies just above the Upper Freeport coal and outcrops over a great part of this quadrangle, and the Pittsburg sandstone, which overlies the Pittsburg coal and is found in the southern portion of the quadrangle between Long Run and Blacklegs Creek.

The village of Avonmore, which has a population of about 700, derives its water supply from wells sunk in the sands and gravels of the river terrace on which it is built. Elderton, which is the next largest place, with a population of 300, is dependent on private wells sunk to bed rock.

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DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

:OLOGY AND PALEONTOLOGY OF THE JUDITH RIVER BEDS

BY

T. W. STANTON

AND

J. B. HATCHER

WITH A CHAPTER ON THE FOSSIL PLANTS

BY

F. H. KNOWLTON

WASHINGTON

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., May 11, 1904.

SIR: I have the honor to transmit herewith the manuscript of a report on the geology and paleontology of the Judith River beds, by T. W. Stanton and J. B. Hatcher, with a chapter on the fossil plants by F. H. Knowlton, and to recommend its publication as a bulletin.

The report embodies the results of field studies in Montana and adjacent regions during the season of 1903, and of a subsequent study of the collections. By combining careful stratigraphic observations with several lines of paleontologic investigation the authors have satisfactorily answered a much discussed question in Cretaceous stratigraphy, and the results stated in this report will have an important bearing on the geology of a large area in the Northwest.

Very respectfully,

C. W. HAYES,
Geologist in Charge of Geology.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

GEOLOGY AND PALEONTOLOGY OF THE JUDITH RIVER BEDS.

By T. W. STANTON and J. B. HATCHER.[a]

INTRODUCTION.

During the summer of 1903 we spent two months together in the field study of the Judith River and associated formations of northern and central Montana and adjacent areas of Canada. The principal results of this work were the accurate determination of the position of the Judith River beds in the Upper Cretaceous section, and the removal of all doubts as to the correlation of these beds with the Belly River beds of Canada, thus establishing more accurately the position of that Canadian formation. These results are offered as a slight contribution to the Mesozoic history of the north interior region, which is rendered more than usually difficult to decipher because land or nonmarine conditions prevailed during several recurring intervals, at least from the Upper Jurassic to the top of the Cretaceous. It is our purpose to give somewhat in detail the evidence on which our conclusions are based, restricting the descriptions to the areas which have been actually studied by us and which include practically all the known exposures of Judith River beds in Montana and the southeastern part of the Belly River area (including the bottom and the top of the formation) in Assiniboia. After a cursory review of previous work on the formations discussed, the local outcrops and sections in the different areas will be described. The descriptions of the areal and stratigraphic geology will be followed by brief accounts of the vertebrate fauna by Mr. Hatcher, of the invertebrate fauna by Mr. Stanton, and of the flora by Mr. Knowlton.

Working independently along different lines, we have long been interested in the stratigraphic and faunal problems connected with

[a] On July 4, 1904, soon after this manuscript was finished, Mr. J. B. Hatcher died at his home in Pittsburg, after a brief attack of typhoid fever. His death at the early age of 43 years is a serious loss to geology and paleontology, in which the important work he had already done gave promise of greater results in the future.—T. W. S.

the Judith River beds, and both of us had previously visited the typical area near the mouth of Judith River. In 1888 and 1892 Mr. Hatcher spent considerable time in collecting vertebrate fossils from the formation, making only incidental observations on the stratigraphy of the region. He traveled by wagon road, thus approaching the "badlands" exposures of these nonmarine beds from the higher divides, where he noticed outcrops of marine Cretaceous shales in such locations that he inferred that they might overlie the Judith River beds. He had also noticed similar relations of the outcrops on Willow Creek near Musselshell River. The study of the vertebrate fauna led him to the conclusion that it is older than the Laramie fauna of the uppermost Cretaceous. In the absence of data as to the exact age of the underlying formation, all of Mr. Hatcher's observations tended to place the Judith River beds well down in the Upper Cretaceous.

In 1894 Mr. Stanton spent a few days with Mr. W. H. Weed near the mouth of Judith River. They traveled by rowboat down the Missouri River from Fort Benton to Judith, passing over and studying the formations underlying the Judith River beds, beginning with the Fort Benton shales. Mr. Stanton confirmed the statements of previous observers that some of the strata beneath the Judith River beds contain a fauna that is elsewhere characteristic of the Montana group, or Fort Pierre and Fox Hills formations. He was especially impressed by the occurrence, in the upper part of these underlying beds, of a zone containing *Cardium speciosum*, *Mactra alta*, *Tancredia americana*, and other forms which in north-central Colorado are known to occur only in the Fox Hills beds immediately beneath the Laramie. No beds higher than the Judith River were seen, and the view was adopted that the Judith River overlies all of the Montana group and is referable to the Laramie. When a few days later the overlying marine Cretaceous shales were seen in contact with upturned Judith River beds near Havre, Mont., their apparent position was supposed to be due to faulting, of which there was abundant evidence in the neighborhood.

With these divergent views concerning the age of the Judith River beds the writers participated in the renewed discussion on that subject during the winter of 1902–3, to which reference will be made later. Mr. Hatcher then decided to make a field investigation of typical areas of the Judith River and Belly River beds, under the auspices of the Carnegie Museum, in Pittsburg, in which he had charge of the department of paleontology. Mr. Stanton expressed the desire to cooperate in such an expedition, and afterwards arrangements were made under which the expenses of the joint field work were borne by the United States Geological Survey.

DESCRIPTIVE GEOLOGY.

THE STRATIGRAPHIC COLUMN.

In order that the review of previous work on the Judith River beds may be made intelligible without too much circumlocution, it is necessary to introduce here a brief account of the stratigraphy of the Upper Cretaceous in this region. The principal facts, with the names of the new formations recognized, have been published in a preliminary note.[a]

Benton shales.—The lowest formation studied consists of dark clay shales with occasional intercalated bands of sandstone, especially in the upper portion. There are also frequent calcareous concretions, often of large size, which are usually fossiliferous. This is the well-known and widely distributed Fort Benton formation of the Meek and Hayden upper Missouri section. The name is derived from the town of Fort Benton, on Missouri River about 100 miles above the mouth of Judith River, but the original description and especially the stratigraphic limits are based largely on exposures in another area in Nebraska, where the Benton rests on the Dakota sandstone and is overlain by the Niobrara limestone and calcareous shales. In the neighborhood of Fort Benton and in all the region now under investigation there is no limestone corresponding to the Niobrara, and as there is no evidence of an erosion interval or unconformity, it is probably represented by shales or sandstones. The paleontologic indications are that in this region the Niobrara is represented by dark shales not separable stratigraphically from the Benton. If this be true the Benton shales of the upper Missouri represent more than the formation known by the same name in Nebraska, in Colorado east of the Front Range, and at other places, and really include the whole of the Colorado group, so that it is more appropriate to call them Colorado shales, as Weed has done in the Fort Benton folio. These shales are characterized in their lower portion by *Inoceramus labiatus*, *Scaphites warreni*, and a few other species, while toward the top they yield *Inoceramus umbonatus*, *I. exogyroides*, *Pholadomya papyracea*, *Scaphites ventricosus*, *Baculites asper* (?), and many other forms. The species of *Inoceramus* and *Baculites* occur in the Austin limestone of Texas, which is correlated with the Niobrara, and some of them have been found in the upper Niobrara shales of

[a] Science, n. s., vol. 18, 1903, pp. 211–212.

Colorado. The total thickness of the formation is estimated at 800 feet, but only the upper portion, 200 to 300 feet in thickness, is usually seen in the sections examined.

Eagle formation.—Immediately above the Benton shales is the Eagle formation, which was named by Weed from Eagle Creek. It is found along Missouri River for many miles above and below Eagle Creek, the exposures being continuous from a point less than 10 miles below the mouth of Marias River to the mouth of Arrow Creek. At its base it consists of laminated sandstones and shales grading down through 30 or 40 feet into the underlying formation, but its most conspicuous member is a heavy-bedded or massive, very light-yellowish to white cross-bedded sandstone 100 feet or more in thickness, which "weathers into cliffs or steep slopes with balcony ledges and striking monumental forms capped by ironstone masses." (See Pls. I and II.) These striking features of the landscape have been noticed and described by all the early explorers of the upper Missouri. In the neighborhood of Eagle Butte the sandstone is cut by many igneous dikes, which, however, do not cause any vertical displacement.

Above the massive white sandstone are softer beds consisting of alternating sandstones, shales, and many beds and seams of lignite. At many localities bands of small, flat, black pebbles occur near the top. The total thickness assigned by Mr. Weed to the formation along the Missouri is 200 feet, but if the similar lignitiferous beds that are predominantly sandstones be included the thickness is probably more than 300 feet. This greater thickness of beds that can not be consistently separated from the Eagle formation was observed especially on Dog Creek, and at other places in the neighborhood of Judith.

At many places the Eagle formation seems to be barren of fossils. This is especially true of the thick sandstone member. One locality on the Missouri, 7 miles below "Coal Banks," has yielded a few species of fossil plants, and a considerable invertebrate fauna has been collected, mainly from the upper portion, 5 or 6 miles below the mouth of Arrow Creek, and on Dog Creek and elsewhere in the neighborhood of Judith. The invertebrates include *Cardium speciosum*, *Thetis? circularis*, *Mactra alta*, *Placenticeras whitfieldi* (*?*), and undescribed species of *Crenella*, *Leptosolen*, *Baroda*, *Pholadomya*, and *Baculites*, all of which show much closer relation with the fauna of the overlying beds of the Montana group than with that of the Colorado group. This horizon has also yielded a few dinosaurian remains, including the type of *Ornithonimus grandis*, which was found near the mouth of Cow Creek, where the Eagle formation is brought up by faulting.

The formation has often been confused with several other horizons. In addition to the areas already mentioned it has been recognized in

A. EAGLE FORMATION. "STONE WALLS" ON MISSOURI RIVER BELOW MOUTH OF EAGLE CREEK.

Igneous dike in middle distance

B. EAGLE FORMATION. SANDSTONE AND OVERLYING LIGNITE-BEARING BEDS AT MOUTH OF EAGLE CREEK.

prominent outcrops on Flatwillow and Willow creeks, on the Yellowstone at Billings, and on Fish Creek near Musselshell River.

Claggett formation.—The beds to which the name Claggett formation has been given lie above the Eagle formation and below the Judith River beds. In the neighborhood of Judith (old Fort Claggett), where they are well exposed, they have a total thickness of about 400 feet and consist largely of dark clay shales with variable intercalated bands and beds of sandstone, especially in the upper half. The dark shales of the lower part of the formation contain many calcareous concretions, which yield *Gervillia borealis*, *Baculites ovatus*, *Baculites compressus*, and a few other forms, elsewhere regarded as characteristic of the Fort Pierre. The yellowish sandstone beds higher in the formation, especially one about 200 feet from the top and another near the summit, are often locally very fossiliferous, and bear an invertebrate fauna, of which the most conspicuous species are the following:

Species from upper part of Claggett formation.

Tancredia americana.
Cardium speciosum.
Sphæriola? endotrachys.
Tellina equilateralis.
Thracia gracilis.
Liopistha (Cymella) undata.
Mactra formosa.
Mactra alta.
Lunatia subcrassa.
Vanikoropsis tuomeyana.
Baculites sp.

This has long been considered a typical "Fox Hills" fauna, and a number of its species do recur at the top of the marine Cretaceous immediately below the Laramie in Colorado and elsewhere. It is now known that some of them also occur as low as the Eagle formation. The shale exposures of this formation in the neighborhood of Judith have been identified as Fort Pierre in previous publications. The "lower dark shales" mapped by Dawson on Milk River near Pakowki Lake, Assiniboia, are the upper part of the Claggett formation. There is usually a gradual transition upward into the Judith River beds, so that it is often difficult to determine the exact boundary.

Judith River beds.—The lithologic and paleontologic features of this formation are fully described on subsequent pages. The beds are mostly of fresh-water origin, but occasionally contain intercalated brackish-water layers, the most persistent of which is near the top of the formation. More rarely there are local marine deposits in the upper part. The formation is prevailingly light colored and tends to weather into "badlands" forms. The thickness near Judith is little more than 500 feet.

Bearpaw shales.—These shales rest on the Judith River beds, and have the lithologic character of the Pierre shales, part of which they represent. They consist chiefly of dark clays, which weather into rounded slopes and form an "adobe" soil. In certain zones there are

numerous calcareous concretions, most of which are fossiliferous and and yield a varied invertebrate fauna. Among the more common forms are the following:

Species found in Bearpaw shales.

Ostrea patina.
Avicula nebrascana.
Avicula linguiformis.
Inoceramus sagensis.
Inoceramus barabini.
Leda (Yoldia) evansi.
Lucina subundata.
Thetis circularis.
Callista deweyi.
Mactra gracilis.
Liopistha (Cymella) undata.
Anisomyon centrale.
Cinulia concinna.
Anchura americana.
Baculites ovatus.
Baculites compressus.
Placenticeras whitfieldi.
Placenticeras intercalare.
Scaphites nodosus.

This formation is named from the Bearpaw Mountains, around whose north, east, and south sides it is well developed. It is evidently the equivalent of only a part of the Pierre formation, which in South Dakota, Colorado, and elsewhere is defined to include all the strata between the Niobrara limestone and the Fox Hills sandstone. Whether the Bearpaw also includes the representative of the Fox Hills sandstone has not yet been definitely determined. Its limits are precisely the same as those of the beds in Alberta and Assiniboia described by the Canadian geologists as "Pierre-Fox Hills" group, whose thickness is estimated at 750 feet. The thickness in Montana probably approximates the Canadian estimate, but no section where an accurate measurement could be made was studied.

Higher horizons.—Along Musselshell River in the neighborhood of Musselshell post-office and between the Musselshell and the Yellowstone north of Billings and Bigtimber the Bearpaw shales are overlain by a thick series of beds in which sandstones predominate, with shales and several coal-bearing horizons. This series doubtless includes representatives of the Laramie, Livingston, and Fort Union formations as described by Weed in adjacent areas.

HISTORICAL REVIEW.

The earliest definite geologic descriptions of the region about the mouth of Judith River were by Dr. F. V. Hayden, who visited the area in 1854 or 1855,[a] and brought back collections of both invertebrate and vertebrate fossils. The invertebrates were described by Meek and Hayden in the Proceedings of the Academy of Natural Sciences, Philadelphia, beginning in 1856, while the few vertebrate

[a] The scenic features above the mouth of Judith River produced by the Eagle sandstone were described by Lewis and Clark (Expedition to the Sources of the Missouri, etc., 1814) and by Prinz Maximilian zu Wied (Reise in das Innere Nord-America in den Jahren 1832 bis 1834, Coblenz, 1839-1841). The latter gives excellent illustrations of some of the striking outcrops of the Eagle sandstone on pls. 34, 35, 41, and vignette 18.

remains were described by Doctor Leidy.[a] These joint papers by Meek and Hayden, and others written by Hayden independently, contain many notes describing the geology of the Judith River country and varying opinions as to the age of the beds exposed there. The presence of many faults and other disturbances, the lithologic similarity of several distinct formations, and the apparently contradictory character of the evidence from different classes of fossils conspired to make the interpretation of the section difficult, and it is not surprising that the necessarily hasty and imperfect examination of the stratigraphy made by Doctor Hayden left him in doubt as to the relations of some of the beds, or that he made mistakes in attempting to correlate these beds with the Cretaceous section exposed on Missouri River several hundred miles to the east, where the lithologic development of some parts of the section is very different. The members of that section had not then been named, and the formations subsequently called[b] Dakota, Fort Benton, Niobrara, Fort Pierre, and Fox Hills were known as Nos. 1, 2, 3, 4, and 5, respectively.

In these early papers the sandstone now known to form the most prominent member of the Eagle formation was doubtfully referred to "No. 1," but from the fossils that are cited it is evident that Hayden did not separate the sandstone bands of the Claggett formation from the underlying Eagle sandstone. The occurrence of *Hettangia americana* (afterwards referred to *Tancredia*) was especially commented on because it was believed to be a Jurassic type of shell, though its association with *Baculites* and other Cretaceous types was taken as evidence that the horizon was really near the base of the Cretaceous. This marine horizon was recognized to be beneath the nonmarine beds whose invertebrate fossils were all described as Tertiary species. The vertebrate remains from the same region were declared by Leidy[c] to be reptiles and fishes of old types, "which remains, I suspect, indicate the existence of a formation like that of the Wealden." At that time it was not certain whether the vertebrates came from the same horizon as the nonmarine invertebrates or from a lower bed with "No. 1," though apparently Hayden's original opinion was that the bones and part of the fresh-water Mollusca came from the lower horizon and that other fresh- and brackish-water fossils came from Tertiary beds in the same neighborhood, as the following quotation[d] from the first published geologic description shows:

> Some 4 or 5 miles below the mouth of Musselshell River a lower rock—a sandstone—rises above the water level. This is probably No. 1 of the series, No. 2 and

[a] Proc. Acad. Nat. Sci. Philadelphia, 1856, pp. 72, 73, and Trans. Am. Philos. Soc., vol. 11, 1860, pp. 139–154.

[b] Proc. Acad. Nat. Sci. Philadelphia, 1861, p. 419.

[c] Proc. Acad. Nat. Sci. Philadelphia, 1856, p. 73.

[d] Meek and Hayden, idem, p. 114.

No. 3 not being represented here. It is worthy of note that out of two species of *Mactra*, two of *Tellina*, two of *Inoceramus*, one of *Pholadomya*, two of *Natica*, and one *Baculite* found in this rock, not one is known to occur in any of the higher formations, and some of these species are not unlike Neocomian forms.

In consequence of the increasing inclination of the strata, this last-mentioned sandstone rises in the vicinity of North Mountain River [Little Rocky Mountain Creek] as much as 250 feet above the Missouri. Here, or near this, begins a wild and desolate region, known as the *Mauvaises Terres* or Bad Lands of the Judith. At various places in these Bad Lands a sandstone similar to No. 1 was seen alternating with beds of clay and lignite, all of which are upheaved and much distorted. It was found impossible to devote to the examination of these formations time enough to determine their relations to the Cretaceous and Tertiary strata of this region, without running the risk of being cut off from the party and murdered by the Indians. Among a few fossils that were collected here, however, Professor Leidy finds teeth which he refers to two or three genera of large *Saurians* allied to the *Iguanodon*, *Megalosaurus*, etc. There are also in the collection from some of these beds one or two species of Unio, one or more of Cyclas or Cyrena, and a few crushed specimens of *Gastropoda*, like *Paludina* and *Melania*. From these facts we are strongly inclined to think with Professor Leidy there may be here, at the base of the Cretaceous system, a fresh-water formation like the Wealden. Inasmuch, however, as there certainly are some outliers of fresh-water Tertiary in these Bad Lands, we would suggest that it is barely possible these remains may belong to that epoch, though the shells appear to be all distinct species from those found in the Tertiary at other localities in this region.

In this paper the Judith River invertebrates are described as Tertiary species. In a subsequent paper published in the same volume[a] Meek and Hayden again discuss the marine sandstones containing *Baculites* and *Hettangia* [*Tancredia*] *americana*, and suggest that they may be as old as Jurassic, though more probably Cretaceous. Their statement is as follows:

If not older than Cretaceous, we think, from these facts, as well as from the stratigrapical position of these beds, they probably represent some of the older members of that system. What relation they bear to the formations near the same locality in which the saurian remains were found, supposed by Professor Leidy to be allied to the genera *Iguanodon* and *Megalosaurus*, is still an unsettled question.[b]

In 1857 Hayden published his "notes explanatory of a map and section illustrating the geological structure of the country bordering on the Missouri River." Among the "basins of the Tertiary system" he lists[c] the "Bad Lands of Judith River, which occupy an area of 40 miles in length and 15 to 30 in breadth, reposing on a sandstone,

[a] Pp. 265–286.

[b] It is noteworthy that in this article the terms "Judith River beds" and "Judith River formations" are used in a general, untechnical sense to include all the formations occurring near the mouth of Judith River. In Leidy's paper of 1860 "Judith River formation" appears in the title and in the caption of a section. The term was used rather loosely for some years, and when applied strictly to the formation now known by that name it usually took the form "Judith River Estuary beds." In 1871 Hayden proposed "Judith group" (Ann. Rept. U. S. Geol. Surv. Terr. for 1870, p. 97) as a formation name. In subsequent papers by Cope, Meek, and others "Judith River beds" was used with its present signification.

[c] Proc. Acad. Nat. Sci. Philadelphia, 1857, pp. 109–116.

the age of which has not been positively determined." This area is colored as Tertiary on the map, and is described as follows:

This exceedingly interesting deposit occupies a depression in a sandstone formation which rises to the water level at the mouth of Little Rocky Mountain Creek from beneath the well-known Cretaceous bed No. 4 of the vertical section. It presents perhaps the most rugged scenery on the Missouri River, the denudation and erosion having been much greater than at the Bad Lands of White River. But the most remarkable feature of this basin is the wonderful disturbance of the strata. So much are the beds disturbed and blended together by forces acting from beneath, that it seems almost hopeless to obtain a section showing with perfect accuracy the order of superposition of the different strata.

A paper by Meek and Hayden in the same volume[a] gives a further discussion of the subject and shows that the change of view was caused by the study of the invertebrate fauna, which seemed to show close relationship with that of the "Great Lignite basin" near Fort Union.

A Judith River species of turtle (*Trionyx*) had also been identified in a bed at the base of the "lignitic," which was then regarded as Miocene. Their rather guarded statement is as follows:

We would not for a moment hesitate in regarding the deposits of which we have spoken, near the Judith, as Tertiary, were it not for the fact that the saurian and fish remains occurring in these beds, as may be seen by reference to Professor Leidy's remarks respecting them, are allied to Wealden and older types.

In the midst of evidence of such a conflicting nature, it is, of course, unsafe to express any very positive opinion respecting the age of these formations. At the same time we are strongly inclined to the conclusion that they will prove not merely Tertiary, but about of the age of the lowest beds of the Great Lignite basin, or perhaps a little older. We have therefore placed them provisionally along with the Tertiary beds in the accompanying section of the Nebraska rocks.

A generalized section of the Judith River beds 415 feet thick is described as follows:

This section embraces all the deposits, as we believe, seen in the Bad Lands of the Judith, in which land and fresh-water shells are known to occur. They appear, as near as could be ascertained, to occupy a local basin in a series of marine deposits, consisting of beds of sandstone and impure lignite, which we have regarded provisionally as of the age of No. 1 of our general section.[b]

This view, however, evidently was not in harmony with some of Hayden's stratigraphic observations, for when explorations in the Black Hills brought to light a fresh-water fauna at the base of the Cretaceous section, in beds now generally referred to the Jurassic, the opinion as to the age of the Judith River beds was again changed, and in a new edition of Hayden's map[c] the area was colored as "Cretaceous No. 1," with the statement that the beds may be the American

[a] Pp. 117-148.

[b] This section and a general discussion of the geology of the region were also published by Hayden in Warren's "Report of explorations in Nebraska and Dakota," in report of Secretary of War, 1858, reprinted as separate document in 1875.

[c] Proc. Acad. Nat. Sci. Philadelphia, 1858, pp. 139-158.

representatives of the Wealden. A fuller statement by Meek and Hayden[a] is as follows:

> The occurrence of these forms at this horizon [in the Black Hills] also leads us to suspect that a considerable portion of the estuary beds at the mouth of Judith River, above Fort Union, in regard to the age of which we have been so much puzzled, may be, as first suggested by Doctor Leidy, a representative of the Wealden, and as we were then inclined to suppose, belong to our No. 1.
>
> The close similarity between the lithological characters of these deposits and those of some of the Tertiary formations of the Northwest, and the estuary character of their fossils, together with the analogy of many of the species of Mollusca found in one of the upper beds (which may be an outlier of Tertiary resting on older formations), taken in connection with the fact that amongst the fossils collected from one of the middle beds (see section p. 124, Vol. VIII, Proceedings, 1857) there were some fragments of a *Trionyx*, regarded by Doctor Leidy as identical with a species occuring in well-marked Tertiary deposits near Long Lake, below Fort Clark, led us subsequently to think the whole of these estuary beds near the Judith River might possibly be an outlier of Tertiary reposing upon deposits of the age of our No. 1. At the same time, in consequence of the occurrence in them of remains regarded by Doctor Leidy as analogous to *Lepidotus*, *Iguanodon*, and *Megalosaurus*, we stated that in the midst of evidence of such a conflicting nature, it is unsafe to express any very positive opinion respecting the age of these formations.
>
> Since we know that there is a similar group of beds at the base of No. 1, as we now understand it, near the Black Hills, containing a mingling of fresh-water and marine fossils—although we are not sure any of them are specifically identical with those found near the Judith—we are inclined to think our first views in regard to these Judith River formations will prove to be correct, or, in other words, the beds from which the saurian remains, described by Doctor Leidy, were obtained, will yet prove to be a part of the series we include in No. 1 of the Black Hills section. This view receives additional support, too, from the fact that the Judith River fresh-water or estuary formations were often seen much upheaved and distorted, while around the Black Hills the Tertiary deposits appear to lie undisturbed upon the upheaved older rocks in such a manner as to indicate that the last period of disturbance amongst the strata of this region occurred after the close of the Cretaceous epoch, but previous to the deposition of the Tertiary.

In 1860 Hayden published[b] a paper entitled "A Geological Sketch of the Estuary and Fresh-water Deposit of the Bad Lands of the Judith," which contains perhaps the fullest connected account of the region that he printed. The statements as to the stratigraphic position of the Judith River beds are somewhat equivocal, but show no definite change from the views expressed in the paper last cited. The sandstones of the Eagle formation are referred to "No. 1," and some of the sandstones of the Claggett formation are also referred to the same horizon, while the shales of the Claggett, which are called "No. 4," are said to rest on No. 1.

In the following year Meek and Hayden[c] published a review of the geology of the upper Missouri region as an introduction to a paleontologic paper. Here they first gave the geographic names Dakota, Fort

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[a] Ibid., pp. 45, 46.

[b] Trans. Am. Philos. Soc., vol. 11, pp. 123–138.

[c] Proc. Acad. Nat. Sci Philadelphia, 1861, pp. 415–447.

Benton, Niobrara, Fort Pierre, and Fox Hills groups to the five numbered divisions of their Cretaceous section and called the overlying beds near the mouth of the Yellowstone, and lower on the Missouri, the "Fort Union, or Great Lignite group," at the base of which they placed the Judith River beds. On page 417 the following statement is made:

> At the time we published these facts [concerning the fresh-water Jurassic of the Black Hills], we were led by the discovery here of fresh-water shells, in such a position, to think that some estuary deposits of doubtful age, near the mouth of Judith River, on the Missouri, from which Doctor Leidy had described some saurian remains resembling Wealden types, might be older than the Tertiary. Later examinations, however, have demonstrated, that the Judith beds contain an entirely different group of fossils from those found in the rock under consideration, and that they are really of Tertiary age, and hold a position at the base of the Great Lignite series of the Northwest.

Concerning the marine beds near the mouth of the Judith previously assigned to "No. 1," the authors say that it would be unsafe to refer them to the Dakota group.

In another paper, published by Hayden[a] in 1861, the Tertiary beds of the Northwest are classified as "first, estuary deposits; second, true lignite beds; third, Wind River Valley deposits; fourth, White River Tertiary deposits." Of the first class he says:

> The estuary deposits, of which the Judith basin may be regarded as the type, are quite remarkable and of a most interesting character. Opinions of a somewhat conflicting nature have been entertained in regard to them, owing to the peculiar character of the organic remains, but recent observations have convinced me that they are all of Tertiary age, and that they are quite widely distributed throughout the Far West.

In the subsequent writings of Hayden there are many brief references to the Judith River beds, in which he constantly referred them to the Tertiary, with an occasional expression of doubt as to their exact position. There is no record that he revisited the original Judith River area after his first observations were made, but when connected with the Raynolds expedition of 1859–60[b] he passed over the same horizons and in part recognized them in traveling from the Judith Mountains to the mouth of Bighorn River on the Yellowstone.

Judith group was definitely proposed by Hayden[c] as a formation name in 1871 when discussing the Tertiary as follows:

> There is one other basin near the sources of the Missouri which has already yielded many fossils of great interest, but which seems to be isolated from the others. This is what I have called the Judith basin, and inasmuch as it seems to be one of the ancient lake deposits, and characterized by a peculiar group of organic remains, I will designate the strata as the Judith group. The sediments do not differ materially from those of the Fort Union group, and they contain impure beds of lignite,

[a] Am. Jour. Sci., 2d ser., vol. 31, pp. 229–245.

[b] Rept. Geol. Expl. of the Yellowstone and Missouri rivers by Dr. F. V. Hayden, 1869. See pp. 12, 59, 93, and 94.

[c] Prelim. Rept. U. S. Geol. Survey of Wyoming, p. 97.

fresh-water Mollusca, and a few leaves of deciduous trees. But the most remarkable feature of this group is the number and variety of the curious reptilian remains, of which we have only yet caught a glimpse.

In 1875 the announcement was made independently by Meek[a] and by Hayden[b] that the marine sandstones near the mouth of Judith River whose position had so long been in doubt had been correlated by means of fossils with the Fox Hills. This correlation was based on the discovery of a fauna in a sandstone occurring at several localities in the South Platte Valley within a few miles of Greeley, Colo. The sandstone was referred to the Fox Hills, doubtless correctly, on account of its position at the top of the marine Cretaceous and beneath the Laramie, and because a large majority of the seventeen molluscan species recognized in it were known to be characteristic of the Fox Hills elsewhere. With these Fox Hills species there were four forms, *Tancredia americana*, *Cardium speciosum*, *Mactra formosa*, and *Mactra alta*, that had previously been known only from the Judith River country, in sandstones that we now refer in part to the Claggett formation, though part of the species range down into the Eagle. Meek says:

> From this blending together of the Fox Hills species and those of the marine Cretaceous beds found at the mouth of Judith River on the Upper Missouri it is evident, I think, that we can not be far wrong in regarding the latter beds as holding a position at the horizon of the top of the Fox Hills group.

The correlation was justified by the facts then available, but it is now known that some of these littoral species have a vertical range of many hundreds of feet and are not distributed throughout that interval in any one section, but recur whenever the conditions were suitable.

In Meek's last work,[c] published in 1876, there is an excellent résumé of the stratigraphy, in which he says:[d]

> We have long regarded the Judith River beds as forming a distinct group older than the Fort Union deposits.

He again identifies the beds underlying the Judith River as upper Fox Hills, and thinks it highly probable that the Judith River beds are Cretaceous, while the Fort Union may be Lower Eocene.

Prior to this time E. D. Cope had begun his contributions to the discussion. In his paper entitled "Synopsis of the Extinct Batrachia, Reptilia, and Aves of North America"[e] he listed the Judith River vertebrate fossils as Upper Jurassic species, probably meaning by that the Wealden. In 1874[f] he regarded the Judith River beds as the top of the Cretaceous and discussed them under the heading "Fort Union or Lignite group." Three years later, after a field season in the area,

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[a] Bull. U. S. Geol. and Geog. Surv. Terr., vol. 1, pp. 39, 40.

[b] Idem, p. 403.

[c] A report on the invertebrate Cretaceous and Tertiary fossils of the upper Missouri country: Rept. U. S. Geol. Surv. Terr., vol. 9.

[d] Page xlvii.

[e] Trans. Am. Philos. Soc., vol. 14, 1870, pp. 1–252.

[f] *Bull. U. S. Geol. and Geog.* Surv. Terr., vol. 1, No. 2, pp. 6–8.

Cope[a] published his "Report on the Geology of the Region of the Judith River, Montana," in which some stratigraphic and paleontologic details are given. The Judith River beds are treated as a distinct formation, about 500 feet thick, immediately overlying the Fox Hills, and the dark shales now included in the Claggett formation are called "Fort Pierre," while other areas of shales on the Missouri farther east, which doubtless overlie the Judith River, are not recognized as distinct or in a different position. The white sandstone of the Eagle formation is tentatively correlated with "No. 3," or Niobrara, on account of its stratigraphic position. Cope's view as to the age of the Judith River beds is expressed in the following quotation:[b]

> The positive evidence, then, as to the age of the Judith River fauna is that it is Cretaceous, but, as might be supposed from its position, with some Tertiary affinities.
>
> * * * * * * *
>
> I will remark in conclusion that it is probable that the Lignitic formation will come to be regarded as a primary division of the Cretaceous, and equivalent as a whole to all or part of the older marine series. It will include as subdivisions the Judith River and Fort Union epochs, as already defined by Mr. Meek from the invertebrate fossils, and probably the Laramie or Bitter Creek epochs as distinct from them.

Similar views as to the classification and stratigraphic succession of the beds were expressed by Edward S. Dana and George B. Grinnell,[c] who visited the region in 1875. They spoke of the disturbed condition of the beds, but erroneously attributed it to the effects of local landslides, denying that there were any real faults or uplifts.

The review given thus far is confined to work on the original area in Montana. Meanwhile, however, the area of similar formations not far to the north and west in Canada began to be investigated. The first paper having any important bearing on the present subject was by James Hector[d] and was entitled "On the Geology of the Country between Lake Superior and the Pacific Ocean (between the Forty-eighth and Fifty-fourth Parallels of Latitude)." He gives a general section of the Cretaceous formations, at the base of which he places a great lignite-bearing group, including in it all the coal-bearing strata observed, although he admits that it may contain two distinct horizons, one Upper Cretaceous or Eocene and the other Cretaceous in the position assigned to it at the base of the section. His map extends as far south as Missouri River, where all the areas now known to consist of Eagle, Claggett, and Judith River formations are colored as the lowest member of his section.

The same region was more fully described in 1875 by Dr. George M. Dawson,[e] who then treated all the coal-bearing beds as Tertiary

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[a] Bull. U. S. Geol. and Geog. Surv. Terr., vol. 3, pp. 565–597.

[b] Idem, pp. 576 and 577.

[c] Geological Report in Ludlow's Rept. Reconnaissance from Carroll, Mont., to Yellowstone National Park and Return, pp. 97–137, Washington, 1876.

[d] Quart. Jour. Geol. Soc. London, vol. 17, 1861, pp. 388–445 and map.

[e] British North American Boundary Commission. Report on the Geology and Resources of the Region in the Vicinity of the Forty-ninth Parallel from the Lake of the Woods to the Rocky Mountains.

and of the same horizon, though he recognized considerable differentiation in the widely separated areas and made stratigraphic observations that suggested a lower position for some of them. He speaks of the striking resemblance of the eastern (Souris River) area of Lignite Tertiary to the "typical Fort Union," while the badlands south of Wood Mountain have a somewhat different aspect, and westward from this point there is a gradual change until near the Buttes [Sweetgrass Hills] the appearance is entirely distinct. This western area includes the beds that were afterwards described as the Belly River series, whose correlation with the Judith River beds is first suggested[a] in the following words:

> Though I have not yet had an opportunity of comparing the fossils obtained in the western marine and brackish-water beds of the Tertiary on the forty-ninth parallel with those from the Judith River beds of the Missouri, I have little doubt of the identity of the formations. The age of these Judith River beds has long been an unsettled question, and they have only lately been included by some geologists with the remainder of the Lignite Tertiary and called Cretaceous. Doctor Hayden was only prevented from calling them Fort Union Tertiary by the occurrence of certain vertebrate remains—the meaning of which is now better understood. The lithological resemblance between these beds of the line and those of the Judith River is close.

A few vertebrate fossils are described in an appendix by Cope, who calls them Fort Union. Part of them are from Judith River beds on Milk River and the others from probably a much higher horizon near Wood Mountain.

In 1881 Dawson[b] described the Cretaceous section of the Peace River region in Athabasca and named the Dunvegan sandstone, a partly nonmarine formation, intercalated in the marine Cretaceous, which he correlated at that time with the Niobrara and later with the Belly River beds. Subsequent descriptions and references by McConnell[c] and by Whiteaves[d] indicate that its exact position is still uncertain, and as it lies far north of the area we have examined it need not be further considered except to remark that it may represent either the Eagle or the Judith River formation.

Dawson returned to a more detailed study of the western plains immediately north of the international boundary and soon discovered that a part of the beds he had previously grouped under the Lignite formation as Tertiary really underlies marine Cretaceous shales referred to the Fort Pierre. This lower formation was called the Belly River series, and in the preliminary announcements[e] was correlated with the Dunvegan, and also doubtfully with the Niobrara. In the official report just referred to the section shows Laramie at the

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[a] Pp. 156, 157.

[b] Ann. Rept. Geol. Surv. Canada, 1879–80, p. 115B. See also Am. Jour. Sci., 3d ser., vol. 21, pp. 391–394, and Canadian Naturalist, new series, vol. 10, pp. 20–22.

[c] Ann. Rept. Geol. Surv. Canada, 1890–91, n. s., vol. 5, pt. 1, pp. 54–55D.

[d] Trans. Roy. Soc. Canada, vol. 11, 1893, sect. 4, pp. 9, 10.

[e] Rept. Geol. Surv. Canada for 1880–81–82, pp. 1–23B, 1883. Trans. Roy. Soc. Canada, vol. 1, 1883, sect. 4, pp. 42, 43.

top, consisting of the named subdivisions Porcupine Hills, Willow Creek, and St. Mary River, succeeded below by unnamed yellowish sandstones and shaly beds, with a mingling of fresh-water and brackish or marine mollusks, still referred to the Laramie. Beneath these are Fox Hills and Pierre beds. The lower part of the section, beneath the Pierre, is described as follows:

Belly River series.—Sandstone, shales, and sandy clays, generally of pale grayish tints. Marine and fresh-water fossils.

Series apparently underlying the last on the Bow and Belly, but on the stratigraphical position of which some doubt yet remains owing to the resemblance of its estuarine fauna to that of the Judith River. Brownish and yellowish sands and clays.

The Judith River beds are treated as a part of the Laramie, and the correlation of the Belly River beds is indicated in the following statements:

The pale beds underlying the Pierre in this region represent, with little doubt, the Dunvegan sandstones of the Peace River section. They are also evidently identical with those described by Professor Cope as occupying a similar position on the Missouri [now known as the Eagle formation]. This subdivision, which appears most probably to hold the position of the Niobrara in the Nebraska section, is therefore one of great persistence in the Cretaceous.

The same correlations are made in the paper published by the Royal Society of Canada.

In 1884 Dawson[a] extended the Belly River beds downward to include the yellowish and brownish sands and clays with a Judith River fauna, and repeated the correlation of the upper part of the formation with the Eagle sandstone, while suggesting a lower position for the Judith River beds. He says:

The upper part of the Belly River series evidently represents the pale, sandy beds which occur on the Missouri in a similar position with reference to the Pierre; and the latter holds coal or lignite at the base in this district, as described by Prof. E. D. Cope, on that river.

In reference to the fossils, he makes the following very proper suggestion:

The fossils of the Belly River series have not yet been critically examined; but their resemblance to those of the Judith River is so complete that I am strongly inclined to revert to Messrs. Meek and Hayden's original views respecting the stratigraphy of the latter beds and to suggest, though with some hesitation, that the species figured on pls. 37–39 of Meek's work on the Cretaceous and Tertiary fossils of the upper Missouri, as from a peculiar development of the Fox Hills group, have really been derived from beds underlying the Pierre.

The species referred to are from near the mouth of Judith River and are now known to have come from the Claggett and Eagle formations.

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[a] Science, n. s., vol. 3, pp. 647, 648.

Dawson's final report[a] on the region in the vicinity of Bow and Belly rivers, Northwest Territory, published in 1885, gives detailed descriptions of the Belly River and associated formations and a full statement of the evidence for its accepted stratigraphic position beneath about 830 feet of marine Cretaceous correlated with the Fort Pierre and Fox Hills. The area mapped extends from a few miles south of the international boundary to latitude 51° 20′ and from longitude 110° 45′ to the Rocky Mountains. The Belly River beds are represented as covering a large area, broadening southward across the eastern portion of the map. West of this area of Belly River beds overlying formations occupy a low, broad syncline, while in the uplifted belt along the foothills of the Rocky Mountains all the Cretaceous formations are mapped together under one color, because the complex region was not studied in sufficient detail. In the general section Dawson assigns maximum thicknesses to the formations as follows: To the members of the Laramie 5,750 feet; Fox Hills, 80 feet; Fort Pierre, 750 feet; Belly River, 910 feet; "Lower dark shales," 800 feet.

The conclusions as to the Belly River and Judith River beds are summarized in these words:[b]

> Briefly stated, it would appear from the investigations now reported on that considerable areas of the beds which in 1874 I called "Lignite Tertiary"—here and in previous announcements designated as Belly River series—must be relegated to a position below the Pierre shales, or at least to one below an upper portion of these shales. The beds thus separated as the Belly River series were, in 1875, by me correlated with the Judith River series of the Missouri. Additional and extensive collections of fossils since obtained and now being worked out confirm and strengthen this correlation and lead to the presumption that the so-called Judith River series must also occupy a position well down in the undoubted Cretaceous. It may be added that this was the view originally held by Messrs. Meek and Hayden, and supported, it would appear, not alone on the supposed analogies of the vertebrate remains examined for them by Professor Leidy, but also on stratigraphical evidence—evidence which perfectly agrees with the impressions resulting from such cursory examination as I was able to make of the Missouri sections from the deck of a steamer while ascending the river in 1881.

An incidental reference in a footnote on page 122c makes it evident that Dawson still failed to discriminate between the Eagle and the Judith River formations on the Missouri, and he did not recognize any horizon in his area corresponding to the Eagle formation. It seems remarkable that this formation, which is so well developed on the Missouri only about 75 miles south of the Canadian boundary, should disappear completely from the sections in the Sweetgrass Hills and along Milk River near the boundary. Several facts gleaned from Dawson's careful descriptions and from the subsequent paleontologic report[c] favor the suggestion that the Eagle sandstone really occurs

[a] Geol. Surv. Canada, Rept. Prog. for 1882–1884, pp. 1–169c and map.
[b] Idem, p. 119c.
[c] Cont. Canadian Palæont., vol. 1, pt. 1, 1885.

here and has been referred to the Belly River. The castellated sandstones along Milk River between Verdigris Coulee and Dead Horse Coulee, as described on page 40c and as figured[a] in an earlier report, resemble the Eagle sandstone much more closely than any part of the Judith River or any other horizon in the general region. This same sandstone horizon was recognized in Rocky Spring Ridge and on the west flank of West Butte (Sweetgrass Hills) resting on dark shales which at the last-named locality have an estimated thickness of 800 feet. Now, this thickness is much too great for the shales of the Claggett formation, which underlies the Judith River and is the same as that of the Fort Benton shales beneath the Eagle. Dawson expressly states[b] that the dark shales of these two localities do not agree very satisfactorily with those farther east on Milk River, at the mouth of Pakowki Coulee, which we now recognize as belonging to the Claggett formation, and the fossils reported from them at both West Butte and Rocky Spring Ridge include *Baculites asper* and *Scaphites warreni*, of which the latter especially is a characteristic Fort Benton species. As the writers have not visited the localities nor seen the fossils in question, they can only suggest that possibly the structure has been misinterpreted and that part of the area mapped as Belly River really belongs to the Eagle formation.

The invertebrate fossils of the Belly River beds and associated formations have been described by Prof. J. F. Whiteaves,[c] and the fossil plants have been treated by Sir William Dawson,[d] with stratigraphic notes by Dr. George M. Dawson. Their general conclusions as to the evidence of the fossils are expressed in the following quotations. Whiteaves says:

> Judging by their respective invertebrate faunas, it would seem impracticable to separate the "Belly River series" from the Laramie, and more especially from the "Judith River group," on purely paleontological evidence.[e]
>
> The invertebrate fauna of the "Belly River series" seems to be essentially the same as that of the "Laramie" of the United States and Canada, unless more than one formation has been confounded under the latter name, and * * * it is at present scarcely possible to separate the "lower dark shales" of Doctor Dawson's Bow and Belly River report from the "Fort Pierre and Fox Hills" groups, on purely paleontological grounds.[f]

Sir William Dawson states in the first and third papers cited that "it scarcely seems possible to distinguish by fossil plants alone the lower Laramie beds from those of the Belly River." He also remarks that the Dunvegan series of the Peace River region probably corre-

[a] Rept. Prog. for 1880–1882, frontispiece of Doctor Dawson's report.
[b] Geol. Surv. Canada, Rept. Prog. for 1882–1884, p. 125c.
[c] Cont. Canadian Palæont., vol. 1, pt. 1, 1885.
[d] Trans. Roy. Soc. Canada, vol. 3, sec. 4, pp. 1–22, 1886. Idem, vol. 4, sec. 4, pp. 19–34, 1887. American Naturalist, vol. 22, 1888, pp. 953–959.
[e] Cont. Canadian Palæont., vol. 1, pt. 1, 1885, p. 55.
[f] Idem, p. 89.

sponds in time with the Niobrara. The paleontologic evidence and relationships will be fully discussed on later pages.

Additional areas of Belly River beds on the east and north of Dawson's area were described and mapped by R. G. McConnell[a] and by J. B. Tyrrell,[b] respectively, who confirmed Dawson's conclusions concerning the stratigraphic position of the formation so far as the overlying beds were concerned, but still left the exact age of the underlying formation undetermined.

In the United States the discussion concerning the age of the Laramie continued long after Meek and Hayden's publications ceased; and since the Laramie was generally held to include or to be the equivalent of the Judith River beds, the age of the latter was frequently involved in the discussion. The paleobotanists Newberry, Lesquereux, and Ward contributed many articles to this controversy, but they had no direct bearing on the Judith River question because no definitely described fossil plants were known from the Judith River beds.

From 1877 to 1891 Dr. C. A. White published many papers in which the invertebrate paleontology and the geologic relations of the Judith River beds are more or less fully treated. At first[c] the Judith River was treated as a separate formation immediately underlying the Fort Union and holding the same relative position as the Laramie in southern Wyoming, but in the following year the term "Laramie" was used in a broader sense, as follows:

> The Laramie group includes as either subordinate groups or regional divisions both the Judith River and Fort Union series of the Upper Missouri River; the Lignitic series east of the Rocky Mountains in Colorado; the Bitter Creek series of southern Wyoming and adjacent parts of Colorado; and also the Bear River Estuary beds, together with the Evanston coal series of the Valley of Bear River and adjacent parts of Utah.[d] * * *
>
> Some of the known portions of this great group doubtless represent different stages of the Laramie period, but the members just designated are, as a rule, understood to represent different geographical developments of its strata with modifications of its fauna rather than separate successive epochs of time in the geological period which is represented by the whole great group. The proof of the identity of these widely separated portions of the Laramie group consists in the recognition of various species of fossil mollusks in all of them that are found in some one or more of the others, thus connecting the whole by faunal continuity. Similar proof has also been obtained by Professor Cope in the discovery of certain species of vertebrate fossils in more than one of these geographical members of the Laramie group.[e]

So far as the Judith River, Fort Union, and Bitter Creek beds are concerned these views are consistently held in all of White's subse-

[a] Ann. Rept. Geol. Surv. Canada, n. s., vol. 1, 1886, pp. 1-78c.
[b] Idem, vol. 2, pp. 1-152e, 1887.
[c] Bull. U. S. Geol. and Geog. Surv. Terr., vol. 3, 1877, pp. 608-609.
[d] Idem, vol. 4, 1878, p. 721.
[e] Idem, p. 865.

quent papers. In 1883, accompanied by Prof. Lester F. Ward, he visited the Judith River and Fort Union areas along the Missouri, but he did not see any reason for changing the later conclusions of Meek and Hayden and of Cope, and his stratigraphic observations were not fully published. Concerning the Fort Union area he made the following statement:[a]

> During the summer of 1882 I gave especial study to the geology of the region about Fort Union, extending up the Yellowstone Valley, and including all the localities from which Doctor Hayden obtained the fossil plants here referred to [Fort Union plants described by Newberry]. The result of that study has been to ascertain that only one formation, namely, the characteristic Fort Union group, which is nothing more or less than a part of the great Laramie group, occupies that whole region. That is, with the exception of one or two small exposures of the Fox Hills Cretaceous group, upon which the Laramie strata rest conformably, no other than Laramie strata are to be found there.

In the excellent correlation paper on the Cretaceous, White[b] gave a general discussion of both the Laramie[c] and the Belly River[d] formations, with a review of the literature. He still included the Judith River, Fort Union, etc., in the Laramie and held that it was deposited in a great land-locked sea of mainly brackish waters.

Concerning the Belly River beds he states that "certain observed conditions of strata exposed along the Missouri River in northern Montana apparently indicate its presence there. It also seems not improbable that some of the strata in the upper part of the valley of the Musselshell River, in Montana, which have been referred to the Laramie,[e] really belonged to the Belly River formation." The first reference is evidently to the occurrence of the Eagle formation between Fort Benton and Judith, and the second reference is probably to an actual occurrence of Judith River beds which will be referred to again. The position of the Belly River formation is thus stated:

> The marine strata which overlie the Belly River are certainly referable to the Montana formation, but whether they represent the whole of that formation or not it is at present impossible to say. That is, it is not yet certainly known whether the Belly River formation is interposed between the top of the Colorado and the base of the Montana, or between a large upper and a small lower part of the last-named formation. The former condition is assumed to exist, although it is not yet certain that some of the fossil species discovered beneath the Belly River strata do not also occur in the Montana formation.

From the intimate relationship between the Belly River and Laramie faunas, especially the specific identity of certain gill-bearing Mollusca in both, White inferred that there must have been physical continuity between the formations. The assumed relations of the Belly River to

[a] Am. Jour. Sci., 3d ser., vol. 26, 1883, p. 121.
[b] Bull. U. S. Geol. Survey No. 82, 1891.
[c] Pages 145–153.
[d] Pages 173–177.
[e] See Lindgren, W., Tenth Census of the United States, vol. 15, pp. 743–746.

the associated formations are shown diagrammatically by representing the Belly River formation as a wedge inserted between the Colorado and Montana groups, gradually thickening so as to replace more and more of the Montana, until in some hypothetical area it becomes continuous with the overlying Laramie and is not separable from it.

In 1886 Mr. W. Lindgren[a] published a description, with sections, of a region between the Yellowstone and Musselshell rivers in Montana that is now known to contain Judith River beds. The section as described is remarkable for the very great thickness (8,600 feet) of beds assigned to the Laramie, and for the intercalation of marine beds with *Placenticeras* and *Baculites* within the Laramie. The writers have traveled along the line of Lindgren's section that extends northeasterly from Billings, and according to their interpretation the sandstone forming the cliffs at Billings, which he referred to the Fox Hills, really belongs to the Eagle formation, and his Laramie must include the Claggett, Judith River, and Bearpaw, as well as the Laramie and probably some overlying formations.

Cope[b] briefly discussed the Belly River beds of Canada in 1887. He stated that the flora and the fauna, vertebrate and invertebrate, are identical or nearly so with the Laramie, and expressed a suspicion that there had been some error of observation.

About this time horned dinosaurs began to be recognized at various localities in the West, and the beds yielding them were called by Prof. O. C. Marsh[c] Ceratops beds and referred to a single horizon of the Laramie. Mr. J. B. Hatcher, who had done the field work in collecting the vertebrate faunas of these beds, maintained that there was paleontologic and stratigraphic evidence that they include at least two horizons. His views are expressed in the following quotations:[d]

> The actually known area of the Ceratops beds is indeed very limited, and from these areas we should exclude certainly the Judith River or upper Missouri, and very likely the Black Butte locality in southwestern Wyoming. The beds of the former certainly and those of the latter almost certainly belong to an older horizon than those of the Denver or Converse County localities; the latter may be considered as the typical locality for the Ceratops beds. All of the dinosaurs from the Judith River country are smaller, less specialized forms than those from the Converse County and Denver localities, as has already been observed by Marsh.

Speaking of the Converse County locality, he says:

> It would doubtless be better to restrict the limits of the Ceratops beds to those strata in which horned dinosaurs occur, and to consider the underlying 400 feet of barren sandstones as the equivalent of the Judith River beds. * * *
>
> The terms Fox Hills and Laramie as now used can not be taken to represent distinct and different periods of time, for, as has been shown by G. M. Dawson,

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[a] Tenth Census United States, vol. 15, pp. 743–746.

[b] American Naturalist, vol. 21, 1887, pp. 171, 172, and 445–462.

[c] Am. Jour. Sci., 3d ser., vol. 38, 1889, p. 501. Marsh definitely referred the Judith River beds to the same horizon as the Ceratops beds of Converse County, Wyo., in the Geology of the Denver Basin: Mon. U. S. Geol. Survey, vol. 27, 1896, p. 478.

[d] *American Naturalist*, vol. 30, 1896, pp. 116, 117.

Selwyn, and McConnell in the Belly River region in Canada, and frequently observed by the writer on the upper Missouri in Montana, marine beds with typical Fox Hills fossils have been found interstratified with fresh and brackish water beds containing characteristic Laramie fossils, showing conclusively that the two periods were in part at least contemporaneous; the one representing the marine and the other fresh or brackish water forms existing at the same time and in not widely separated regions, these alternations in the nature of the fauna in the same locality having been brought about by successive encroachments and recessions of the sea.

In 1896 Mr. Whitman Cross[a] discussed the age of the Arapahoe and Denver formations and referred to related beds in other regions, especially those yielding horned dinosaurs. He suggested that "the Judith River strata may perhaps represent the Arapahoe or some other post-Laramie formation, and not the true Laramie of Colorado and Wyoming." He quoted from the manuscript notes of Mr. T. W. Stanton the description of a section on Dog Creek, near Judith, Mont., which includes the lower 300 feet of Judith River beds and underlying strata then referred to the Fox Hills, but now designated as the Claggett and the upper part of the Eagle formation.

Mr. W. H. Weed[b] has described the section in the region of the Crazy Mountains between Yellowstone and Musselshell rivers, where the Judith River beds are now known to exist, but he failed to recognize the formation. It is very probable that the brackish-water fossils cited[c] as coming from the Livingston formation north of the Crazy Mountains were collected from an outcrop of Judith River beds.

In the Fort Benton folio,[d] published in 1899, Weed named and described the Eagle formation, stating that it rests on the Colorado shales and is overlain by 2,000 feet of marine beds referred to the Montana formation, and that it has yielded fossil plants similar to those of the Belly River beds. The area mapped on the Missouri is west of all the outcrops of Judith River beds.

A few fossil plants from the Eagle formation near "Coal Banks" on the Missouri were described by Dr. F. H. Knowlton[e] in treating the flora of the Montana formation. These were described as Belly River species, and in justification of this correlation a brief manuscript note by Stanton, giving his views on the stratigraphy and correlation of that part of the section, was published. The concluding portion of Stanton's note is as follows:

It is evident from the stratigraphy and from the marine invertebrate fauna of the underlying and overlying strata that the sandstones and the associated coal beds and

[a] Geology of the Denver Basin: Mon. U. S. Geol. Survey, vol. 27, pp. 239–241.

[b] The Laramie and the overlying Livingston formation in Montana: Bull. U. S. Geol. Survey No. 105, 1893. The Fort Union formation: Am. Geologist, vol. 18, 1896, pp. 201–211.

[c] Bull. U. S. Geol. Survey No. 105, p. 33.

[d] Geologic Atlas of the United States, folio 55.

[e] Bull. U. S. Geol. Survey No. 163, 1900. This paper was submitted for publication before the Fort Benton folio was issued, and consequently the name Eagle is not used for the formation.

plant-bearing horizons in the neighborhood of Coal Banks on the Missouri River are on essentially the same horizon to which the Belly River series was assigned by Dr. G. M. Dawson, and to which a part of the Canadian beds so named undoubtedly belong. But in Doctor Dawson's full and careful description of the Belly River series it is pointed out that in certain areas referred to that series the stratigraphy is not clear, and the beds may overlie the Montana shales instead of underlying them. It happens that most of the Belly River fauna, which consists chiefly of Laramie species, was collected in those doubtful areas. I suspect that in Canada two distinct formations, separated by marine beds, have been confused under the term Belly River series, and that a large part of the fauna, and possibly also of the flora, was collected from the upper horizon, which included the Laramie and possibly even later beds.

In 1902 Mr. Earl Douglas[a] described a formation under the local name Fish Creek beds, which he correctly correlated with the Belly River. The locality is a few miles east of the Crazy Mountains area previously described by Weed. The Eagle formation also occurs in the section, but was called Niobrara.

In the same year the vertebrate fauna of the Belly River beds in Canada was reviewed and described by Prof. H. F. Osborn[b] and Mr. L. M. Lambe, the former contributing the general discussion and the latter the paleontologic descriptions. The conclusions as to correlation and stratigraphic position were more concisely stated in an abstract by Osborn,[c] from which the following brief extracts are taken:

> The [Canadian] Survey had established beyond question, geologically, that the Belly River series is mid-Cretaceous, that it underlies the Montana or Fort Pierre-Fox Hills group, and overlies the Fort Benton and Dakota groups. * * * It soon appeared * * * that the Belly River vertebrates were of decidedly different and apparently of older type than those from the Laramie beds of Converse County, Wyo., described by Marsh, and were rather to be compared with those described by Leidy, Cope, and Marsh, from Montana, chiefly from the Judith River beds, which overlie the Fort Pierre in a region by no means distant geographically.
>
> * * * * * * *
>
> The fossil land vertebrates hitherto described from Montana probably are, in part at least, of mid-Cretaceous or Belly River age, although the true Judith River beds certainly overlie the Fort Pierre and are of more recent age.

Hatcher[d] commented on the paper last cited, correcting a statement concerning the locality of certain fossils, and giving reasons for believing that the stratigraphic position of the Judith River beds is lower than the horizon to which he assigned them in 1896. Stanton[e] replied to this note, asserting that the formation in question overlies the Pierre and Fox Hills, called attention to the Eagle formation, and again suggested that two or more horizons may have been confused in the Belly River beds of Canada.

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[a] Proc. Am. Philos. Soc., vol. 41, pp. 210, 211. The section is partly described in an earlier note. (Science, n. s., vol. 15, 1902, pp. 31–32.)

[b] On Vertebrata of the mid-Cretaceous of the Northwest Territory: Cont. to Canadian Palæont., vol. 3, pt. 2, 1902.

[c] Science, n. s., vol. 16, 1902, pp. 673–676.

[d] Idem, pp. 831–832.

[e] *Idem, pp. 1031–1032.*

Prof. S. W. Williston[a] contributed to the discussion in a note on the Laramie of Converse County, Wyo., holding that these deposits as well as the Judith River are contemporary, in part at least, with the Fox Hills, and that the fauna presents in some respects "a startling resemblance to that of the Judith River and Belly River series."

Additional notes bearing on various phases of the discussion were published during 1903 by Osborn,[b] Hatcher,[c] C. H. Sternberg,[d] and O. P. Hay,[e] and ending with a brief note by Hatcher and Stanton[f] on "the stratigraphic position of the Judith River beds and their correlation with the Belly River beds," in which they give the principal results of the field work which is fully described in the present paper.

DESCRIPTION OF JUDITH RIVER BEDS, BY AREAS.

ORIGINAL AREA.

GENERAL FEATURES.

The history of the exploration of the region along Missouri River near the mouth of Judith River and of the description of its geologic and topographic features by Dr. F. V. Hayden has been briefly given in preceding pages. While some of Doctor Hayden's determinations and correlations have since been shown to be erroneous, as was to be expected from the pioneer nature of his work, the reader of his most extended sketch,[g] if familiar with the region, can not fail to be impressed with his ability as an observer and the fidelity and clearness with which he describes the chief geologic features of the country.

The following extracts from Doctor Hayden's paper are quoted here as bearing directly upon the stratigraphic limits and geographic distribution of the Judith River beds as originally understood and defined by that author:

> Near the mouth of the Judith River, not far from the sources of the Missouri, in latitude 47° 30′, longitude 109° 30′, is a wild, desolate, and rugged region which I have called the "Bad Lands of the Judith," in contradistinction to those of White River. No other portion of the upper Missouri country exhibits the effects of erosion and denudation on so large a scale, and to add to the picturesque effect of the country the variegated strata are distorted and folded in a wonderful manner by the action of the subterranean forces that have elevated the mountain masses in the vicinity. The surface of the country occupied by the deposit I am about to describe is cut up into ravines and canyons, with nearly vertical sides, rising to a height of 400 to 600 feet above the bed of the river, with scarcely a tree or shrub to greet the eye of the

[a] Science, n. s., vol. 16, 1902, pp. 952–953.
[b] Idem, vol. 17, pp. 356, 357.
[c] Idem, pp. 471, 472, and Am. Geologist, vol. 31, pp. 369–375.
[d] Science, n. s., vol. 17, pp. 870–872.
[e] Am. Geologist, vol. 32, pp. 115–120.
[f] Science, n. s., vol. 18, pp 211–212.
[g] Trans. Am. Philos. Soc., 1860, pp. 123–138, with a map.

explorer. A few scattering pines cap the summits of the hills and draw a scanty nourishment from a thin, dry soil, but it may be regarded for the most part as an inaccessible desert suited only as a retreat for the buffalo and mountain sheep.

The area occupied by this peculiar basin I could not determine with precision, but have estimated it at about 40 miles from east to west and from 15 to 30 from north to south, and it is separated into two nearly equal portions by the Missouri. The Judith River rises in the Judith Mountains, pursues a course nearly due north, for the most part through Cretaceous strata, and empties into the Missouri in latitude 48°, longitude 106°. The Judith River forms the north [western] boundary of this basin. The Muscleshell River also rises near the Judith Mountains, but takes a course a little east of north, flows through Cretaceous formation No. 4, and empties into the Missouri near latitude 47° 30′ and longitude 108°. That portion of the "Bad Lands" which is formed of the estuary deposit under consideration lies between these two streams. About 30 miles north of the entrance of the Judith River into the Missouri is the Bear's Paw Mountain, a small range, the highest peak of which is elevated about 2,000 feet. On the same side of the Missouri and in nearly a northeasterly direction are the Little Rocky Mountains, a range similar to the Bear's Paw, though apparently disconnected from it. On the south side of the Missouri, about 15 miles southwest of the mouth of the Judith, the Square Buttes may be seen rising 400 or 500 feet above the surrounding prairie, and are the nearest upheaval of trappean rocks to the Missouri in this region. From 30 to 50 miles south is quite an extensive range, called the Judith Mountains, which have not yet been explored geologically. Here comparatively small local upheavals seem to represent the dying out of the intense subterranean forces which uplifted the vast Rocky Mountain chain. It will be important to understand the geographical position of these mountains in order to fully appreciate the sources of the power which has disturbed the strata of the more recent fossiliferous rocks, a point which will be again referred to in this paper.

Lewis and Clarke, in their interesting account of an expedition to the sources of the Missouri, gave a brief but accurate description of the physical features of this remarkable region, but dwell more in detail on the picturesque portions near the "Stone Walls," which are composed of a basis strata upon which the estuary deposits of the "Bad Lands" of the Judith rest, which are doubtless of the age of Cretaceous formation No. 1, or upper Jurassic.

In the above description there are some errors relating to the geography, such as the statement that Musselshell River rises near the Judith Mountains; and the sandstones ("Stone Walls" of Lewis and Clarke) upon which, according to Hayden's statement, the estuary deposits of this region rest, were erroneously identified with Cretaceous No. 1, although they are now known to represent the Eagle formation and to be immediately underlain by the Benton and overlain by the Claggett formation. However, the stratigraphic limits of the Judith River beds are fixed with reasonable accuracy, while the geographic limits of the type exposure is very accurately outlined on the map accompanying his paper.

From Doctor Hayden's paper and the personal observations of the present authors the original area of the Judith River formation may be defined as lying between the mouths of Judith River on the west and Little Rocky Mountain Creek on the east and extending both north and south of Missouri River for an average distance of about 20

miles. Throughout almost this entire region typical and characteristic exposures of these beds are everywhere observable. They rest, with at least apparent conformity, upon the darker-colored marine sandstones and shales of the Claggett formation, and in certain favored localities are overlain by material resembling the typical Pierre shales, in this region known as the Bearpaw shales. As these shales are soft and friable they yield readily to erosion, and over large areas, especially in the vicinity of Missouri River, where erosion has been most rapid, they have been completely carried away and the Judith River beds appear as the uppermost of the series. This fact, together with the resemblance between the lithology and fauna of the underlying marine sandstones and those of the Fox Hills sandstones in the regions farther south, for years caused many geologists to mistake the true stratigraphic position of the Judith River beds, and to refer them unhesitatingly to the Laramie. In certain localities, however, the Bearpaw shales have resisted erosion and are seen in their normal position conformably above the harder and lighter-colored beds of the Judith River formation. This is especially true on Cow Creek, a small northern tributary of the Missouri rising in the eastern end of the Bearpaw Mountains. At many places along this stream the Bearpaw shales rest upon the Judith River beds, and along the old Fort Benton and Cow Island trail between Cow Creek and the southeastern extremity of the Bearpaw Mountains the Judith River beds are overlain by about 600 feet of these shales.

The Judith River beds of this region consist of light ash-colored sandstones, alternating with usually darker colored and more friable shales and clays mingled with frequent seams of lignite, which in places, more especially toward the top of the series, attain considerable importance, not infrequently forming beds of fairly pure lignite with a thickness of several feet. The most important and most constant of this series of lignite seams occurs very near the top of the Judith River beds and is frequently overlain by a shell breccia from 1 foot to 3 feet thick, and in most instances is composed almost entirely of the shells of *Ostrea subtrigonalis*, although at some places *Corbicula cytheriformis*, *Corbula subtrigonalis*, and other brackish-water forms are common.

The average thickness of the Judith River beds in this region is about 500 feet, if there is included in them the brackish (sometimes apparently purely marine) beds at the top and bottom of the series. These brackish beds are lithologically very similar to the intermediate fresh-water deposits, which are frequently rich in the remains of fresh-water Mollusca, and contain also in some abundance, but usually in a very fragmentary condition, the bones and teeth of fresh-water fishes and reptiles and of terrestrial dinosaurs. Everywhere through these beds

fossil plants are found in considerable abundance, but usually are not well preserved.

The frequency with which the different strata of sandstones and clays replace one another, both laterally and vertically, together with the great disturbances that have taken place subsequent to the deposition of the Judith River beds, renders it extremely difficult, if not impossible, to fix upon any definite horizons or strata within the limits of the fresh-water series that may be followed and recognized with certainty, even in reasonably adjacent sections. A detailed section taken at any point is of little value, since a similar section made at a distance of only a mile or two would give a quite different sequence of the alternating strata of sandstones and shales.

Almost every traveler has noted the complicated folding and faulting. Grinnell and Dana[a] attributed these disturbances to landslides due to the action of water, but Cope[b] pointed out the error of this view. No better description of the frequency of these disturbances, and the difficulties they have caused the stratigrapher, can be given than that of Doctor Hayden, which is as follows:[c]

> It presents perhaps the most rugged scenery on the Missouri River, the denudation and erosion having been much greater than at the Bad Lands of White River. But the most remarkable feature of this basin is the wonderful disturbance of the strata. So much are the beds disturbed and blended together by forces acting from beneath that it seems almost hopeless to obtain a section showing with perfect accuracy the order of superposition of the different strata.

EXPOSURES ON DOG CREEK.

Although the deposits under consideration were named from Judith River, they are rather poorly represented on that stream. They are well shown in the bluffs of Dog Creek, a small tributary emptying into the Missouri from the south, about 2 miles below the mouth of Judith River. The exposures on Dog Creek and on the north side of Missouri River immediately opposite the mouth of Dog Creek have been most frequently visited by geologists and paleontologists, and are therefore the best known of all the areas of the Judith River beds. Here, unfortunately, the beds are not of much value to the paleontologist, and are even more unsatisfactory to the stratigrapher, since the overlying Bearpaw shales are not adequately represented.

Dog Creek, or Dog River, as it is given on some maps, rises in the Moccasin Mountains, a small outlier of the Judith Mountains. After leaving these mountains it flows for perhaps 25 or 30 miles in a northerly direction through a narrow and shallow valley with rolling, grass-covered table-lands on either side. At intervals along the banks

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[a] Geol. Rept. in Ludlows's Rept. on a Reconnoissance from Carroll, Mont., to Yellowstone National Park, 1876, pp. 97–137.

[b] Bull. U. S. Geol. and Geog. Surv. Terr., vol. 3, pp. 565–597.

[c] *Proc. Acad. Nat. Sci. Philadelphia*, 1857, pp. 115–116.

of the stream and its tributaries and on the slopes of the steeper hills exposures of the sandstones and shales of the Judith River beds may be seen. About 12 or 15 miles above its mouth the stream leaves this comparatively open country and enters a deep, rugged canyon. The surrounding country now suddenly changes from a rolling, grass-covered plain to a wild, desolate, but picturesque region, deeply dissected by numerous canyons, presenting mile after mile of almost perpendicular walls with jutting headlands capped with spires and minarets or flanked perhaps by numerous pillars detached from the perpendicular sides of the canyon wall, each threatening at any moment to add its towering mass to the talus-covered slope below. About the crest of the bluffs are considerable forests of pine and spruce which formerly afforded a sufficient supply of fuel for the river steamers that plied between Fort Benton and the lower Missouri. A few of these trees may also be seen clinging even to the perpendicular cliffs of the canyon walls, while on the less rugged slopes there is a sparse and scattered growth of small shrubs and bushes belonging for the most part to the genus *Artemisia*. In favored localities, especially at the summits of landslides, where disturbances in the beds have formed small basins which receive and retain the moisture brought by heavy rains, the chokecherry, *Prunus virginiana*, often forms considerable thickets. In the bottom of the canyons the banks of the streams are fringed with broad and long-leaved cottonwood, while scattered about and often forming impenetrable thickets are buffalo or bullberry bushes. Such are the badlands of the upper Missouri. The nature of the topography made this region the last retreat for the larger game animals of this district. The inaccessible nature of the region afforded these animals their greatest protection, and they lingered here long after they disappeared from the surrounding plains and mountains. This was especially true of the deer and bighorn or mountain sheep, both of which animals were still abundant when the region was first visited by one of the present writers in 1888. During our visit the past season, however, the mountain sheep seemed to have been nearly or quite exterminated, while only a few deer remained.

Dog Creek flows through this badland country in a deep and rugged canyon until it emerges upon the narrow valley of the Missouri, about a mile above its mouth. The walls of the canyon on either side are composed for the most part of the light ash-colored sandstones and darker shales and clays of the Judith River beds. This is especially the case in the upper portion of the canyon. In the lower half of the canyon the darker buff-colored sandstones and dark sandy or black clay shales of the underlying Claggett formation constitute a considerable portion of the bluffs. For considerable distances the Judith River beds are nearly or quite horizontal, and conformably overlie

the Claggett formation in such a manner that it is difficult to determine where one formation ends and the other begins, although in the field a bed of yellowish brown sandstone varying in thickness from 1 foot to 20 feet or more was regarded as the upper limit of the Claggett formation. This bed of sandstone appeared fairly constant, not only in this, but in other areas of the exposures, and it was referred to in our notes as the *Tancredia* sandstone, owing to the presence in it in considerable abundance of fossil shells belonging to that genus. From the persistence of this sandstone and from the fact that it marked the beginning of a decided change in the lithology of the underlying and overlying beds it would certainly form a convenient delimitation between the two series of deposits, and should perhaps be considered as the uppermost member of the Claggett formation, notwithstanding that in a number of instances typically marine fossils extended for some distance above in the basal members of those lighter-colored sandstones and shales usually referred to the Judith River beds and generally considered as entirely of fresh- or brackish-water origin.

At frequent intervals along the canyon of Dog Creek the beds are much disturbed by faults and folds, and at several places not only the Claggett formation is exposed, but the underlying Eagle sandstones have been thrust up and appear as prominent cliffs. (See Pl. II.)

On the east side of Dog Creek 1 mile above its mouth the Eagle sandstones are seen near the bottom of the valley dipping westward at various angles. They continue to appear at frequent intervals for 2 miles farther up the creek, and at a distance of 1 mile above the mouth of the canyon on the west side of the creek they cap the higher bluffs. In this vicinity the Eagle formation is composed of an upper and a lower stratum of light-colored, heavy-bedded sandstone, separated by a series of lignites and shales, the latter near the bottom bearing *Baculites* and other marine invertebrates. Above the upper and below the lower strata of sandstones are arenaceous shales and thin-bedded sandstones and lignites. The upper of these bear *Cardium speciosum* and *Mactra alta* in great abundance. On the west side of the creek the crest of the divide between Dog Creek and Judith River is composed entirely of the Claggett and Eagle formations and the underlying Benton shales. The Benton shales are not well exposed in any section seen in this vicinity.

At the point where Dog Creek leaves the canyon and opens into the valley of the Missouri, a prominent cliff or butte of upper Eagle sandstones is seen on the east side of and not far from the creek. It is very fossiliferous, and from it the following invertebrates were secured:

Species found on Dog Creek.

Cardium speciosum.
Tellina montanaensis.
Baroda? sp.
Callista sp. cf. C. deweyi.
Mactra alta.
Mactra formosa.
Lunatia subcrassa.

CLIFF OF UPPER EAGLE SANDSTONE NEAR MOUTH OF DOG CREEK.

A little farther up and on the same side of the creek the following section was obtained:

Section on Dog Creek.

	Feet.
9. Lower Judith River beds with a heavy bed of brown sandstone at base resembling the *Tancredia* sandstone mentioned above, but apparently destitute of fossils. The overlying lighter-colored beds yield many fresh-water invertebrates	200
8. Black shales weathered in gentle slopes with numerous concretions containing *Baculites ovatus*, *Placenticeras*, *Inoceramus*, and other marine invertebrates. The whole referred to the Claggett formation. The sandstone bands of the upper half with *Tancredia*, etc., are not well exposed in this section	300
7. Cross-bedded, sometimes finely laminated, light-colored sandstones and fine conglomerates with harder layers and concretions weathering brown, and lenses containing *Cardium speciosum*, *Mactra alta*, etc., especially abundant toward the top. An additional 20 feet of soft sandstones and arenaceous shales forms the transition to the Claggett formation	100
6. Light, soft sandstone and shale	90
5. Arenaceous shale with 1 to 3 foot band of very impure lignite in middle	10
4. Yellowish sandstones consisting at base of 1 to 3 foot band of hard sandstones with ferruginous masses, overlain by 8 feet of finely laminated sands and thin lignite seams, passing above into 30-foot bed of yellow, massive, coarse sandstone with thin seams of lignite, overlain by 1 foot of lignitic sands, followed by 20 feet of soft buff sandstones	60
3. Soft sandstones and shales consisting at base of 10 to 15 feet of soft, usually light-colored sandstones, passing upward into more shaly material having at top a few feet of light sands. More shaly layer yielded *Placenticeras whitfieldi*	60
2. Sandstone with *Thetis? circularis*, *Leptosolen*, *Baroda*, *Pholadomya*, *Lunatia*, *Placenticeras*, *Baculites*, etc., regarded as base of Eagle	3–5
1. Benton shales with very hard grayish concretions. Lower 40 feet consists of rather soft shales, the upper 35 feet of more arenaceous and harder shales; no fossils	75

For a distance of between 5 and 8 miles from the mouth of Dog Creek the beds in the bluffs of the creek continue practically horizontal and undisturbed. The light ash-colored sandstones and shales of the Judith River beds are exposed to a thickness of from 300 to 400 feet and form the greater portion of the canyon's walls, but the upper members of the Claggett formation are still seen at the bases of the cliffs. While in this portion of the canyon the rocks appear undisturbed, not far to the east of the creek two prominent folds may be seen extending for several miles in a northwest-southeast direction, and along the crest of these the sandstones and shales of the Claggett formation appear flanked on either side by the Judith River beds.

A little farther up Dog Creek, in undisturbed areas, the Claggett formation disappears beneath the bed of the stream and the bluffs of the canyon are formed entirely of the Judith River beds, which have a maximum thickness here of perhaps 500 feet and are composed below of alternating layers of light ash-colored sandstones and darker shales

abounding in numerous fresh-water Mollusca. Such invertebrates as *Unio*, *Anodonta*, *Sphærium*, *Physa*, *Planorbis*, and *Goniobasis* are common, while the remains of *Trachodon*, *Ceratops*, *Monoclonius*, *Deinodon*, *Palæoscincus*, *Ischyrotherium*, *Trionyx*, *Emys*, *Crocodilus*, *Lepidotus*, *Myledaphus*, etc., represent the vertebrate life of the period.

Toward the top of the series the characteristic light-colored sandstones and shales of the Judith River beds give way to darker-colored lignites and shales, which are usually overlain by a stratum of shell breccia or marl ranging from a few inches to 3 feet in thickness, and composed for the most part of the shells of *Ostrea subtrigonalis*, indicative of brackish waters and a later return of marine conditions. These upper beds are well shown on Dog Creek where it leaves the grass-covered plain and enters the canyon, and also on its tributaries. In the plains country to the south the highest hills are capped with the *Ostrea subtrigonalis* layer of the upper Judith River beds. The upper part of the Judith River beds in this region has the same general appearance as on Cow Creek, about the foot of the Bearpaw Mountains, near Havre on Milk River, and on Sage Creek in Canada. It is well shown on an eastern tributary of Dog Creek, where, a few miles from its junction with the main stream, a heavy bed of lignite 5 to 10 feet thick is underlain and overlain by 10 to 15 feet of light, soft sandstone capped by the *Ostrea subtrigonalis* layer, which in some places contains shells of *Corbicula cytheriformis*, *Corbula subtrigonalis*, *Goniobasis convexa*, etc., in considerable abundance. In some exposures there is a thinner bed of lignite above or below the main lignite seam, with an *Ostrea* layer immediately capping it. About 3 miles east of Dog Creek and on the south side of the tributary mentioned above the uppermost *Ostrea* bed is overlain by about 30 feet of black shales with concretions, but no fossils were found in them. These shales resemble very closely the Bearpaw shales, and doubtless represent the base of that formation.

EXPOSURES ON BIRCH CREEK.

Birch Creek rises in the Bearpaw Mountains and flows south, emptying into Missouri River nearly opposite the mouth of Dog Creek and about 2 miles below the mouth of Judith River. A short distance below the point at which it leaves the mountains it enters a canyon, which, like Dog Creek Canyon, is deep and rugged and is cut in the Judith River and underlying formations. Above this canyon the hills on either side of the creek are formed of the Bearpaw shales.

The creek leaves the mountains by two branches, the east and west forks, known respectively as Birch Creek and Little Birch Creek. On the east side of Little Birch Creek, near the foot of the mountains and just below the Fort Benton–Cow Island road, the Judith River beds are brought to the surface by a prominent northeast-southwest anti-

A. BIRCH CREEK CANYON FROM TOP OF BLUFFS NEAR MOUTH.

Looking toward Bearpaw Mountains. Shows full thickness of Judith River beds and top of Claggett formation

B. BROKEN ANTICLINE OF EAGLE SANDSTONE ON NORTH SIDE OF MISSOURI RIVER 1 MILE BELOW MOUTH OF BIRCH CREEK.

Judith River beds form the more distant cliffs on right

cline and protrude from beneath the Bearpaw shales. On either side of this anticline the Judith River beds dip gently and soon pass beneath the Bearpaw shales.

A few miles west of Little Birch Creek, 1 mile above the bridge on the east fork of Eagle Creek, locally known as Dog Creek, a ridge of Judith River beds runs in a northeast-southwest direction and dips northwesterly, toward the mountains, at a high angle and soon passes beneath the Bearpaw shales.

Between the point where Birch Creek enters the canyon and Missouri River the adjacent country is deeply dissected. It is a typical badland region and presents all the features already described as prevailing in the badlands of Dog Creek on the opposite side of the Missouri (Pl. III, *A*). The beds composing the canyon walls have in some places been much faulted and folded, often in such a complicated manner as to render difficult the determination of the proper sequence of the strata.

One mile above its mouth Birch Creek has cut its way through a prominent anticline which extends for several miles in a north of west by south of east direction, and brings to the surface the Eagle and Benton formations. About 1 mile below Birch Creek this anticline is faulted and in the bluffs of a small canyon opening into the Missouri about 300 feet of Benton shales appear beneath an escarpment of yellowish-brown Eagle sandstones which here forms a most conspicuous topographic feature (see Pl. III, *B*). At this locality the upper Eagle sandstone is in places very fossiliferous, and such forms as *Cardium speciosum*, *Thetis* (*?*) *circularis*, *Callista*, *Leptosolen*, *Baroda*, *Pholadomya*, and *Baculites* are very common. Above the Eagle sandstones are about 400 feet or more of shales and sandstones belonging to the Claggett formation. The lower 200 feet or more consist of dark shales weathering to soft clay on the slope and containing *Baculites ovatus*, *Placenticeras whitfieldi*, and *Gervillia borealis*. About 200 feet below the top of the formation is a band of brown sandstones and shales about 30 feet in thickness, with *Avicula nebrascana* (*?*), *Sphæriola endotrachys*, *Tancredia americana*, *Tellina equilateralis*, and *Lunatia subcrassa*. Above this bed are frequent bands of sandstone intercalated in the shales, and one of these, about 160 feet higher and therefore very near the upper limit of the formation, yielded practically the same fauna, as follows: *Cardium speciosum*, *Tancredia americana*, *Sphæriola* (*?*) *endotrachys*, *Mactra formosa*, *Liopistha* (*Cymella*) *undata*, *Lunatia subcrassa*, and *Baculites* sp.

The upper portion of the Claggett formation is well exposed on the east side of Birch Creek 1½ miles above its mouth, at the first bend in the creek, just above the point where a difficult and little-used trail descends from the east. At this point about 20 feet of dark, sandy, and rather compact shale at the base are overlain by 10 to 15 feet of

yellowish-brown sandstone with sharks' teeth, *Tancredia americana*, and other invertebrates in abundance. Then come 30 feet of arenaceous shales, followed by 5 feet of sandstone overlain by 40 feet of shale. Then 3 feet of sandstone is separated by about 40 feet of shale from the 5-foot stratum of *Tancredia* sandstone which has been taken as the upper limit of the Claggett formation. This exposure is well shown in Pl. IV, *B*, where the trees mark the limit between the Claggett formation and the overlying Judith River beds, which here have a thickness of 510 feet from the *Tancredia* sandstone at the base to the *Ostrea subtrigonalis* layer at the top. The overlying Bearpaw shales are not represented in this immediate region, having been entirely removed by erosion. It was from the sandstones near the base of the Judith River beds near the mouth of Birch Creek that Professor Cope in 1876 secured the type of *Monoclonius crassus*. From this point for a distance of 2 or 3 miles up Birch Creek the Judith River beds are quite undisturbed and present a continuous section from their base to the *Ostrea subtrigonalis* zone.

EXPOSURES ON MISSOURI RIVER BETWEEN BIRCH AND COW CREEKS.

On either side of Missouri River between Birch and Cow creeks the country is deeply dissected and presents the appearance of a wild badland region (see Pl. IV, *A*). As on the lower courses of Dog and Birch creeks, the rocks belong to the Judith River beds and the underlying Claggett formation, save at intervals where disturbances in the strata have brought to the surface the Eagle sandstones and underlying Benton shales. Everywhere in the vicinity of the river in this region the overlying Bearpaw shales have been removed by erosion. In places, however, not far from the river, especially on the south side near Cow Island, these shales overlie the Judith River beds, while they occur almost continuously along the old Benton and Cow Island trail along the southern foot of the Bearpaw Mountains between Birch and Cow creeks. From Bearpaw Springs, at the southeastern base of these mountains, this trail continues westward over the Bearpaw shales with only occasional exposures of the underlying Judith River beds at intervals in the bluffs of the coulees. At Black Coulee, about 6 or 8 miles west of Bearpaw Springs, the Judith River beds outcrop from beneath the Bearpaw shales only a half mile below the point where the road crosses the bed of the coulee, and 1½ miles farther down the coulee is a larger similar exposure. At the upper of these two exposures a section on the east side of the creek shows at the top a 1-foot bed of shell breccia with *Ostrea subtrigonalis*, *Corbicula*, *Corbula*, and *Anomia*, underlain by 20 feet of light sandy clays followed by 10 feet of lignite underlain by an ash-colored sandstone with thin seams of lignite to bed of creek. These beds have a northerly dip of about 15°

A MISSOURI RIVER BELOW MOUTH OF BIRCH CREEK.

Looking downstream.

B. CLAGGETT FORMATION AND OVERLYING JUDITH RIVER BEDS ON BIRCH CREEK.

The contact is marked by the small pine trees.

and are overlain by the Bearpaw shales with nodules containing *Baculites ovatus*, *Placenticeras whitfieldi*, and *Inoceramus*. At the next lower bend in the creek the beds are still inclined to the north, but in the succeeding exposure the crest of a low anticline appears, and below this the beds dip to the south and soon pass beneath the Bearpaw shales, which occupy a basin between this and the more important exposure of Judith River beds already spoken of as occurring farther down the creek. The upper exposures of these Judith River beds contain *Ostrea subtrigonalis*, *Anomia gryphorhynchus*, and *Corbicula cytheriformis*, and a bed a few feet lower yielded *Sphærium planum*, *Campeloma vetula*, *Goniobasis invenusta*, and other fresh-water forms.

Just to the left of the point where the Benton and Cow Island trail begins its descent into the valley of Sand Creek in going west toward Benton the upper Judith River beds dip northward at an angle of 30° and pass beneath the Bearpaw shales. A stratum of brown sandstone a few feet thick and about 100 feet below the top of the Judith River beds yielded *Sphærium planum*, *Sphærium recticardinale*, *Goniobasis sublævis*, and *Campeloma vetula*(?). Farther down the creek better exposures of the Judith River beds are to be seen, and at several places along the Benton trail near the forks of Sand Creek the Judith River beds are overlain by the Bearpaw shales, while 2 or 3 miles still farther downstream extensive exposures of the Judith River beds are capped by the Bearpaw shales.

EXPOSURES ON COW CREEK.

Cow Creek flows in a deep, rugged canyon from a place a short distance below the point where it leaves the Bearpaw Mountains to its confluence with the Missouri. On the east side of Cow Creek and at its mouth there is a prominent exposure of Eagle sandstone (see Pl. V). At this point these sandstones have been uplifted and form a conspicuous ledge extending for several miles in a nearly north-south direction and dipping to the west at an angle of about 45°. These sandstones at this locality yielded the type of *Ornithomimus grandis* Marsh. Another nearly parallel and very similar exposure of the Eagle sandstones crosses 2 miles above the mouth of Bull Creek, a small tributary of the Missouri just below Cow Creek.

The bluffs on both sides of Cow Creek for several miles above its mouth are made up largely of rocks belonging to the Claggett formation overlain by the lighter-colored materials of the Judith River beds. The rocks here do not differ materially from those already described as belonging to the same formations on Dog and Birch creeks farther up Missouri River. At frequent intervals the beds are much faulted and disturbed and the underlying Eagle sandstones and Benton shales are exposed.

About 6 or 7 miles above its mouth Cow Creek is crossed by a dike

of igneous material, in places attaining a thickness of 10 feet. On the east side of Cow Creek about a mile below this dike is a section in which are exposed about 200 feet of Judith River beds overlain by the Bearpaw shales, and which is different from all other sections examined, as it contains a strictly marine horizon well within the limits of the Judith River beds. The section is as follows:

Section on east side of Cow Creek.

	Feet.
12. Dark shales of the Bearpaw formation	200
11. Similar ash-colored sands or arenaceous clays	25
10. Ash-colored sands with many *Ostrea subtrigonalis*	1
9. Lignite	4
8. Soft ash-colored sandstone	40
7. Lignite	1–4
6. Very soft buff sandstone	10
5. Ash-colored arenaceous clays with bands and nodules of brown sandstone and occasional nodules of clay-ironstone in lower portion	40
4. Yellowish, more or less lenticular sandstone with teeth of sharks and other fishes and bones of marine and fresh-water turtles	2–5
3. Soft, friable, ash-colored argillaceous sandstone, the upper 2 or 3 feet containing numerous vertebrate remains, including sharks' teeth, mosasaur bones, vertebræ of *Palæoscincus*, *Ischyrotherium*, and a horn core of *Ceratops montanus* (?)	30
2. Yellowish sandstone weathering into large nodular masses	10
1. Soft, friable, light-gray or ash-colored sandstones not well exposed. A band about 20 feet from the top yielded *Leda*, *Nucula*, *Tellina*, *Liopistha* (*Cymella*) *undata*, *Mactra warrenana* (?), *Lunatia*, and *Placenticeras* (?). These are mostly not specifically determinable, but they indicate a strictly marine fauna	30

The upper lignite and the *Ostrea* bed (Nos. 9 and 10) may unquestionably be assigned to the horizon that has been recognized throughout this region as belonging near the top of the Judith River formation, and all of the beds below No. 12 must be assigned to that formation on account of their stratigraphic position and general lithologic character. The land and fresh-water vertebrates found 100 feet below the *Ostrea* bed belong to the Judith River fauna, while the marine mosasaurs found with them and the marine invertebrates occurring 60 feet lower show plainly that locally the conditions under which the formation was deposited were different from those that generally prevailed. As these marine beds appear to pass horizontally into fresh-water deposits within a short distance, it is probable that they were laid down in a narrow bay or inlet which was not very far west of the ocean.

Farther up Cow Creek the Judith River beds form an increasing proportion of the walls of the canyon, and about 13 miles above its mouth the bluffs are composed of them exclusively, save at intervals where disturbances have brought the underlying marine deposits to the surface.

FAULT CONTACT OF HIGHLY INCLINED EAGLE SANDSTONE WITH HORIZONTAL JUDITH RIVER BEDS NEAR MOUTH OF COW CREEK.

About 10 miles above the mouth of Cow Creek, at the point where the old Fort Benton and Cow Island freight road leaves the creek and turns westward toward the Bearpaw Mountains, there is a conspicuous fault in the Judith River beds, which is shown on Pl. VI, *B*. North of the fault for some distance up the creek and almost uninterruptedly westward to the base of the Bearpaw Mountains the Bearpaw shales conformably overlie the Judith River beds. This is the locality mentioned by Hatcher[a], where, in 1888, he observed about 400 feet of what appeared to be Pierre shales overlying the Judith River beds.

Immediately south of the fault mentioned above, a prominent ridge composed of sediments belonging to the Judith River beds projects into the valley of the creek. The type of *Ceratops montanus* was obtained near the summit of this ridge, and the beds yielded also the remains of *Trachodon mirabilis*, turtles, crocodiles, and fishes of Judith River types and a considerable number of fresh-water invertebrates, including *Unio danae*, *Unio primævus*, *Sphærium planum*, *Sphærium recticardinale*, *Goniobasis invenusta*, *Goniobasis judithensis*, *Physa copei*, *Hyalina occidentalis*, and *Valvata montanaensis*.

Near our camp, at the point where a new trail enters the valley from the west, 2 or 3 miles above the point where the old Fort Benton and Cow Island trail leaves the valley, is an area that is extremely interesting and will therefore be described with some detail. On the summit of the bluff west of Cow Creek, just to the left of the Benton trail, a short distance above its junction with the new trail, is an important fault running N. 15° E. and bringing the Judith River beds up on a level with the Bearpaw shales. This fault strikes across the head of one of the tributaries of Cow Creek, and a mile or two below in the valley on either side of this tributary undisturbed Judith River beds underlie the Bearpaw shales in a nearly horizontal position. An aneroid measurement gave a thickness of 535 feet for the Bearpaw shales, assuming them to be horizontal. Just above our camp, on Cow Creek, a sharp anticline crosses the creek in a northwest-southeast direction. Save for this local disturbance the Judith River beds in the immediate vicinity of camp on both sides of the valley of Cow Creek are undisturbed and lie beneath the Bearpaw shales. The base of these shales is here composed of about 25 feet of light-colored shales and sands, 10 feet of rather dark shale at base, and 15 feet of ash-colored arenaceous shales above, with numerous large claystone concretions weathering yellow. The sands contain *Liopistha* (*Cymella*) *undata*, *Mactra warrenana*, *Lunatia subcrassa*, and *Placenticeras whitfieldi*. Above these come 535 feet of typical Pierre (Bearpaw) shales with their characteristic fossils. Below these marine beds, at the base of the hill directly in front of our camp, are exposed

[a] Science, n. s., vol. 16, 1902, pp. 831–832.

75 feet of the upper Judith River beds, consisting of 25 feet of ash-colored sandstones with numerous very large, irregularly conical brown sandstone concretions, underlain by 10 feet of lignite, very impure at base, which in turn is underlain by 40 feet of light-colored sandstones. These beds contain remains of turtles and dinosaurs. At the point of junction between the Judith River beds and the overlying Bearpaw shales there is a 1-foot stratum of shell breccia composed of *Ostrea subtrigonalis* with *Goniobasis convexa* var. *impressa*, *Panopaea simulatrix*, *Corbula subtrigonalis*, *Anomia gryphorhynchus*, *Corbicula cytheriformis*, and *Corbicula occidentalis* (?). The same horizon at another locality in the neighborhood yielded *Viviparus conradi* associated with *Corbicula*, *Ostrea*, and *Anomia*.

One mile below camp on the east side of the creek there is an important uplift, bringing up the entire Judith River series and several hundred feet of the lower marine beds. The section to which the Bearpaw shales are added from exposures west of camp is as follows:

Section on east side of Cow Creek.

	Feet.	Feet.
5. Bearpaw shales, including the marine light-colored sands and shales at base, but not allowing for westerly dip, which, if continuous, as shown in front of exposure on west side of Cow Creek, would give a thickness of nearly, or quite, 700 feet		560
4. Judith River beds, the middle portion covered in bed of creek. One hundred and fifty feet of lower Judith River beds are continuously exposed in the upper section, and one-half mile east, where the Judith River beds are horizontal, a thickness of 490 feet was measured, but the base is not exposed at this point. A shale bed about 30 feet above the base of the formation yielded many leaves of *Trapa? microphylla*, together with abundant fresh-water Mollusca, including *Sphærium planum*, *Sphærium recticardinale*, *Physa copei(?)*, and *Goniobasis subtortuosa*. Another horizon about 300 feet from the top, in the exposure one-half mile east of the section, yielded *Sphærium planum*, *Anodonta propatoris*, *Unio danæ(?)*, *Unio primævus*, *Valvata montanaensis*, *Hyalina? evansi*, *Hyalina? occidentalis*, *Planorbis amplexus*, *Physa copei*, *Goniobasis subtortuosa*, and *Goniobasis gracilenta*		490
3. Claggett formation:		
c. Light-colored shales or sandy clays with band of brown sandstone containing *Tancredia americana* in middle. Top of marine	50	
b. Yellowish-brown sandstones, generally soft, but with harder layers and lenses, with *Tancredia americana*, *Cardium speciosum*, *Tellina equilateralis*, *Liopistha* (*Cymella*) *undata*, *Lunatia subcrassa*, *Baculites* sp., and fragment of vertebrate jaw	20	
a. Dark shales with concretions bearing *Baculites ovatus*, *B. compressus*, *Nucula cancellata*, *Leda* (*Yoldia*) *evansi*, and *Gervillia borealis*. These shales weather much as the Bearpaw, but with a reddish tinge. The concretions are different and		

A. UNDISTURBED JUDITH RIVER BEDS WITH OVERLYING BEARPAW SHALES ON COW CREEK.

The contact is below the pine trees on ridge in middle distance.

B. FAULT CONTACT OF JUDITH RIVER BEDS WITH BEARPAW SHALES ON COW CREEK 10 MILES ABOVE MOUTH.

A. INDURATED OR CONCRETIONARY MASS IN UPPER PART OF JUDITH RIVER BEDS ON COW CREEK 13 MILES ABOVE MOUTH.

B. UPPER PART OF JUDITH RIVER BEDS WITH HEAVY BED OF LIGNITE ON COW CREEK.

Opposite to view on Pl. VI, *A*.

	Feet.	Feet.
3. Claggett formation—Continued. with fewer fossils and not so great a variety. These beds become lighter toward the top, the upper 50 feet containing two seams of thin brown sandstone, each 2 to 3 feet thick	300–400	
Total thickness of Claggett formation		370–470
2. Eagle formation. No fossils:		
e. Cross-bedded and finely laminated sands with thin seams of lignites, in places becoming more massive	125	
d. Very light-colored, fine, heavy-bedded sandstone	40	
c. Heavy-bedded buff sandstones, soft at base, but harder above, and with indurated lenses and numerous large concretions, weathering brown at top. The thickness of b and c is very variable	50	
b. Heavy-bedded buff sandstones with lenses of lignite and shales sometimes exhibiting cross-bedding	30	
a. Regularly-bedded buff sandstones with several thin seams of dark shales	20	
Total thickness of Eagle formation		265
1. Dark Benton shales with *Baculites* and other invertebrates in concretions, and containing several layers of sandstones in upper 100 feet. The following fossils were found in these shales near the base: *Inoceramus* sp., fragments of a thick-shelled form; *Prionotropis?* sp., fragment; *Scaphites ventricosus; Baculites* sp., a slender, strongly nodose form. Several genera of invertebrates not specifically determinable were collected in the upper portion		300

Above our camp for several miles the bluffs of Cow Creek show important exposures of the Judith River beds, everywhere overlain by the Bearpaw shales. These shales are everywhere more or less fossiliferous and near Hedge Brothers ranch, on upper Cow Creek, the following species were obtained:

Fossils obtained on upper Cow Creek.

Gervillia borealis.
Inoceramus barabini
Leda (Yoldia) evansi.
Lucina subundata.
Thetis? circularis.
Lunatia.
Anchura americana.
Cinulia.
Anisomyon centrale.
Anisomyon alveolus.
Baculites ovatus.
Baculites compressus.
Scaphites subglobosus.
Scaphites nodosus.
Placenticeras whitfieldi.

Pls. VI and VII show well the chief lithologic and stratigraphic features displayed by the various horizons in this region.

AREA NEAR HAVRE, MONT.

The most extensive exposures of the Judith River beds in this area are on the north side of Milk River from 1 to 4 miles above the town of Havre, a small station on the Great Northern Railway just north of

the Bearpaw Mountains. This is perhaps the most accessible of all the exposures of these beds. Here is a rather large and picturesque badland region composed entirely of the Judith River beds. On the north side of Milk River about one-half mile above Havre the road crosses a deep gulch by a small bridge. At the point where this gulch emerges from the bluffs into the river valley, about 80 yards above the bridge, there is on its right side a cut bank, some 20 feet in height, showing two seams of impure lignite. The lower and thicker of these is about 6 feet above the bed of the gulch; the upper is thinner and less pure and is about 10 feet higher than the lower. These two lignites are overlain by the Bearpaw shales, though these shales are probably not in position and are somewhat more arenaceous than usual. In them were found in place two limestone concretions, one of which contained shells of *Ostrea patina* and the other *Inoceramus sagensis*. Immediately beneath, in the wash at the bottom of the gulch, but evidently derived from the shales, was found a similar limestone concretion containing *Placenticeras whitfieldi*.

Up the river these lignite seams outcrop at frequent intervals in the bluffs. They rapidly assume a more elevated position and show at this point a decided easterly dip, amounting to perhaps 4° or 5°.

About 100 yards west of the exposure just described a prospecting tunnel has been driven into the lower and more important lignite seam, and between it and the overlying seam is a light horizontally cleaving sandstone.

Three hundred or 400 yards farther west these lignites are no longer visible, having perhaps passed above the present upper limits of the bluffs and been carried away by erosion.

A half mile farther up the river the bluffs on the north side present a picturesque badland area, consisting at the base of 150 to 200 feet of usually light-colored sandstones and clays, with brown sandstone concretions and occasionally thin seams of lignite. (See Pl. VIII, *A*.) In these beds at several horizons were found in considerable abundance dinosaur bones, crocodiles, garpike scales, turtles, and other vertebrates with fresh-water Mollusca, including *Unio danæ*, *Unio supenawensis*, *Anodonta propatoris*, *Sphærium planum*, *Physa copei*, *Goniobasis subtortuosa*, *Goniobasis invenusta*, *Goniobasis judithensis*, etc. The assemblage of fossils as well as the lithologic features of these beds are those of the Judith River beds.

Above these light-colored, fresh-water deposits are two lignite seams which are very similar to those occurring at the locality where the marine fossils were found and bear the same relation to each other. This badland exposure continues for 3 or 4 miles farther up Milk River and the beds in every way resemble the Judith River beds at the type locality.

On the south side of Milk River for 3 miles west of Havre, or to a

A. BADLANDS EXPOSURES OF JUDITH RIVER BEDS ON NORTH SIDE OF MILK RIVER NEAR HAVRE, MONT.

B. UPPER PART OF JUDITH RIVER BEDS AND OVERLYING BEARPAW SHALES ON SOUTH SIDE OF MILK RIVER 3 MILES WEST OF HAVRE, MONT.

point about 1 mile above the mouth of Beaver Creek, are frequent exposures of the Judith River beds, overlain by the Bearpaw shales. The strata in these exposures have suffered much disturbance and are inclined at varying angles, in two or three places being nearly vertical. The exposures are not sufficient to reveal the structure completely, but in general the beds seem to have been folded sharply and faulted to some extent. Wherever the top of the Judith River formation is exposed it is overlain by the Bearpaw shales, with their characteristic fossils. This is especially noticeable in the bluff just below the mouth of Beaver Creek. Here the beds are inclined at a very high angle, perhaps 60°, with a southwesterly dip. At the bottom they are composed of about 200 feet of light-colored sandstones and arenaceous shales resembling the upper Belly River beds, as described by Dawson. These light sandy materials are succeeded by a series of light-colored clays and shales with 8 or 10 seams of lignite, which become thicker and purer toward the top and are overlain by a bed of *Ostrea subtrigonalis*, about 2 feet in thickness. This upper series of light-colored shales, lignites, and oysters has a thickness of about 60 or 75 feet and appears to represent the extreme top of the Judith River formation. It is overlain by dark marine Bearpaw shales, best seen at the foot of the exposure facing Beaver Creek and on the south side of the railroad track, and containing *Inoceramus*, *Avicula linguiformis*, *Modiola meekii*, and *Baculites compressus*.

Below the mouth of Beaver Creek a high ridge that faces Milk River continues a mile or more toward Havre. The upper part of the exposure is composed of the light-colored sands and shales of the Judith River beds. For perhaps half a mile there is exposed a lower thick stratum of heavy-bedded brown sandstone, which outcrops just above the railroad tracks and contains numerous spherical and irregular concretionary masses. This brown sandstone has an observed maximum thickness of about 30 feet. No fossils were found in it, but near its eastern extremity it is immediately overlain by some brown cherts with the shells of *Corbula subtrigonalis* in great abundance. This sandstone may be the top of the Claggett formation.

Above Beaver Creek, in the narrow ridge between this creek and Milk River, the sequence and relative positions of the fresh-water Judith River formation and overlying Bearpaw shales are well shown. (See Pl. VIII, *B*.) In the valley of Milk River a short distance above the mouth of the creek there is a small uplift with the axis running in a northwest-southeast direction. Above this for a distance of 300 or 400 yards, in the bluffs facing Milk River, there is a shallow syncline, the trough of which at its deepest portion is filled with Bearpaw shales containing *Ostrea patina*, *Liopistha* (*Cymella*) *undata*, *Baculites compressus*, and *Placenticeras whitfieldi*. In the uplift just mentioned and in the eastern and central portion of the syncline only the upper por-

tion of the Judith River beds as seen below the mouth of the creek is shown. The lignites and overlying oyster bed, which here contains *Ostrea subtrigonalis*, *Corbicula cytheriformis*, *Anomia gryphorhynchus*, and *Goniobasis convexa*, are especially prominent. On the western limb of the syncline the lower and more arenaceous members appear. Here the entire series is inclined at a higher angle and is clearly seen to pass beneath the Bearpaw shales.

Owing to the disturbances in the beds about Havre, it is not easy to determine in a perfectly satisfactory manner the sequence of the different horizons. This is especially true of the above-described exposures in the bluffs above the town, where, unless one is familiar with the character of the different formations and has determined their true sequence in less disturbed regions, the confusion is indeed perplexing. The most satisfactory locality for studying the Judith River beds in the vicinity of Havre is on the south side of Milk River about 6 miles below Havre, on Boxelder Creek, about 2 miles south of Toledo, a small station of the Great Northern Railway. Here the tops of the high hills are capped with 25 to 50 feet of Bearpaw shales conformably overlying the Judith River beds. Considerable disturbance is noticeable in the bluffs of the creek at this point, but in the hills 1 mile to the north the sequence of the strata is quite evident.

At the Black Diamond Coal Company's mines, 9 to 11 miles southeast of Havre, in a draw on the west side of Boxelder Creek, there is, in the uppermost Judith River beds, a coal vein 6 to 7 feet thick. It has a gentle southerly dip and is overlain by 20 feet of Judith River deposits and 160 feet of Bearpaw shales, from which were collected *Inoceramus sagensis*, *Placenticeras whitfieldi*, *Placenticeras intercalare*, and *Baculites ovatus*. From this point a range of hills, composed at the base of Judith River beds and capped with the Bearpaw shales, extends in a northwesterly direction to near the mouth of Boxelder Creek. The Bearpaw shales here, as elsewhere, in weathered exposures show loose black shales with limestone concretions. Some of the concretions are 12 to 15 feet in diameter and very symmetrical.

EXPOSURES ON MILK RIVER FROM HAVRE TO THE INTERNATIONAL BOUNDARY.

Above Havre the Judith River beds are exposed almost continuously in the bluffs on either side of Milk River to and beyond the international boundary. There are also occasional exposures of the underlying Claggett formation and less frequently of the overlying Bearpaw shales. Although the region is a plains country, the strata have been much disturbed and are faulted and folded in a remarkable manner. In many narrow belts the disturbances are as great as those usually encountered in an intensely mountainous country, though in the larger areas between the disturbed zones the beds

A. UPTURNED JUDITH RIVER BEDS AND BASE OF BEARPAW SHALES ON MEILI COULEE NEAR HAVRE, MONT.

B. CLAGGETT SHALES AND BASE OF JUDITH RIVER BEDS ON MILK RIVER ONE-HALF MILE BELOW PENDANT D'OREILLE, ASSINIBOIA

are practically horizontal. Since the uplifts occurred the country has been planed off by erosion and covered with thin Pleistocene deposits, so that it is only along the modern drainage courses that there is any evidence of such disturbances, and it is not always easy to determine definitely the exact relations of the various strata.

About 5 miles above Havre a small tributary known as Meili Coulee enters the Milk River Valley from the north, about half a mile above a conspicuous red butte, the color of which is due to burned-out lignite seams. At the mouth of Meili Coulee are prominent exposures of the Judith River beds dipping northward at a high angle and overlain by the Bearpaw shales. (See Pl. IX, *A*.) For half a mile before entering the valley of Milk River the bluffs on the east side of this coulee show the following section:

Section on east side of Meili Coulee.

	Feet.
4. Bearpaw shales with *Baculites ovatus* and *Placenticeras whitfieldi*, etc	50
3. Shales underlain and overlain by shell breccia composed largely of *Ostrea subtrigonalis*, forming the top of the Judith River beds	20
2. Lignites, shales, and sandstones	40
1. Light-colored sandstones and shales of the Judith River beds with their characteristic fossils	250

The beds up to this point are inclined at a high angle and dip to the north, and the sequence and relations of the strata are quite evident, but above this point the beds have a different character and are much more nearly horizontal, although they are still gently inclined to the north. At this point in the section the beds have been faulted and the sandstones and shales of the Claggett formation abut against the Bearpaw shales, having been elevated far above their normal position relative to these shales.

Farther up the draw from this point the following section is seen in the bluffs on the east side:

Section on east side of Meili Coulee.

	Feet.	Feet.
2. Judith River beds		
f. Light-colored sandstones and shale with lignite and stratum of shell breccia at the top	100	
e. Sandstones, shales, and thin seams of lignite	130	
d. Shell breccia	3	
c. Shales and lignite	20	
b. *Ostrea subtrigonalis* bed	2	
a. Lignite and shales	20	
		275
1. Sandstones and shales of the Claggett formation with marine invertebrates		160

A little way above its mouth Meili Coulee is crossed by the fault mentioned above. This fault bears N. 60° W. by S. 30° E., and above it the sandstones and shales of the Claggett formation dip gently to the north until, at a distance of perhaps half a mile farther up the coulee, they pass beneath the Judith River beds. In a yellow sandstone layer

near the top of the Claggett formation were collected *Tancredia americana*, *Mactra formosa*, and a few other invertebrates.

Just north of the red butte situated below the mouth of Meili Coulee is a rather extensive exposure of Judith River beds with numerous sandstone lenses and concretions exhibiting cross-bedding and other evidences of strong currents. From these we secured remains of *Trachodon mirabilis*, *Palæoscincus costatus*, and the mammal jaw shown in fig. 1 (p. 100).

In various small draws or coulees between Meili Coulee and Supenaw Coulee, 6 miles farther up the river, conditions similar to those prevailing in Meili Coulee were observed. The fault that crosses Meili Coulee near its mouth is continuous and crosses each of these coulees with about the same trend of N. 60° W. by S. 30° E. This fault crosses Supenaw Coulee about a mile above its mouth and just above Thackeray Brothers' reservoir. Above the fault the sandstones and shales of the Claggett formation dip gently to the north and soon pass beneath the Judith River beds, which here attain their normal development, and at a distance of about 3 miles, or near the head of the west fork of the Coulee, the lignite series at the top of these beds appears in much the same manner as in the other regions described. In Supenaw Coulee the lignite beds are partly burned out and the adjoining clays and sandstones are baked red. They were still burning when visited. Interstratified with these lignites are beds of fresh-water Mollusca, *Campeloma vetula*, and *Unios*, associated with *Corbula perundata*, and three strata of *Ostrea subtrigonalis*.

At the head of Browns Coulee, about 12 miles farther up the river, the Judith River beds are well developed, and on this coulee, about 2 miles above its mouth, is an area of much disturbance, in which a brown sandstone of the lower Judith River beds appears in a steep anticline. There are here two sandstones separated by 30 feet of shales. In the upper of these we obtained shells of *Hyalina occidentalis* and *H. evansi*, dinosaur bones, and fragments of a very large turtle. About 100 yards below this anticline there is a second and larger fold affecting the Claggett formation, which on the north side passes beneath the Judith River beds. The northern limb of this anticline dips at an angle of 45°, while the southern is nearly or quite perpendicular, the sandstones and shales having the appearance of a vertical dike with its southern border resting against the lower brown sandstones of the Judith River beds, which are here only moderately inclined. There is thus unmistakable evidence of a fault as well as a fold at this point.

From Browns Coulee the bluffs of Milk River exhibit frequent evidences of disturbances as far as Simpson's ranch, about 9 miles nearly due south of Wild Horse Lake, which is on the international boundary. About 1½ miles below Simpson's ranch the Judith River beds are well exposed, and we secured remains of *Ceratops*, *Aublysodon*, and *Acipen-*

ser, with *Unio* sp., *Sphærium planum*, *Goniobasis invenusta*, *Goniobasis judithensis*, *Physa copei*, and *Viviparus*.

Above Simpson's ranch, to and beyond the international boundary, disturbances in the beds are less frequent, and the bluffs of the river, which have an average height of about 200 feet, are composed almost entirely of the light-colored sandstones and shales of the Judith River beds.

At Black Butte, a low prominence on the north side of Milk River about 7 miles west of south of Wild Horse Lake, the river valley has a width of scarcely more than a mile and a depth of perhaps 250 feet. The butte stands on the crest of the bluff and, on account of the levelness of the surrounding country, is visible from a considerable distance and forms a rather conspicuous landmark, notwithstanding its low altitude. At the top of this butte are 75 feet of glacial material, beneath which there are about 175 feet of the Judith River beds. At about the middle of the exposure are several feet of shell-marl and in this we secured numerous teeth of *Trachodon*, *Lælaps*, and other dinosaurs, lizards, fishes, etc., together with *Unio priscus* (?), *Unio primævus*, *Sphærium planum*, *S. recticardinale*, *Goniobasis sublævis*, and *G. subtortuosa*.

There are also local developments of cross-bedded brown sandstones with numerous concretions, and these afforded a few vertebræ, teeth, and other remains of *Trachodon*, *Ceratops*, and *Lælaps*.

No lignites were seen here. The upper lignites, so characteristic of the Judith River beds, are wanting in this section and have doubtless been eroded away. They were last seen on the summit of the highest hills about the head of Cottonwood Coulee, 18 miles from Wild Horse Lake, on the road from Havre.

EXPOSURES ON MILK RIVER NORTH OF THE INTERNATIONAL BOUNDARY.

For some distance beyond the international boundary Milk River flows through a narrow and picturesque valley, about 200 feet in depth, carved out of the Judith River beds. A few miles below Pendant d'Oreille, a northwest mounted police station on Milk River about a mile below the mouth of Pakowki Coulee, the uppermost members of the "lower dark shales," as described and mapped by the late Dr. George M. Dawson, appear above the level of the river and occupy successively more elevated positions in the bluffs until, at a distance of about 1 mile above the police station, these shales and sandstones, constituting the Claggett formation, form almost the entire bluffs of the river, the overlying Judith River beds having here been almost entirely removed by erosion. In a bluff on the north side, and at the first bend of the river below Pendant d'Oreille, about 160 feet of beds are exposed (Pl. IX, *B*). The lower 100 feet of this exposure are composed of

the Claggett formation, the "lower dark shales" of Dawson, while the upper 60 feet belong to the Judith River beds, "Belly River series" of Dawson. The section is as follows:

Section on Milk River near Pendant d'Oreille.

	Feet.
8. Light sandstones and soil	10
7. Light sandstones with *Unio* at top	5
6. Light sandstones with shells of *Corbula* at top	19
5. *Ostrea subtrigonalis* breccia	4
4. Light-yellow sandy material	10
3. Impure lignite and shell breccia with *Corbula subtrigonalis, C. perundata, Corbicula cytheriformis, Unio priscus* (?), and *Neritina*	4
2. Light-colored arenaceous shales	20
1. Dark shales belonging to the Claggett formation with limestone concretions and bands of sandstone containing *Nucula, Leda,* and *Liopistha* (*Cymella*) *undata*	100

Nos. 2 to 8 belong to the base of the Judith River beds.

The bluffs of Milk River at the mouth of Pakowki Coulee, immediately above the police camp, are formed almost entirely of marine deposits, consisting, at the base, of dark shales with bands and nodules of limestone and at the top of light-yellow soft sands and arenaceous shales with harder layers of blue sandstones, weathering brown. The latter yielded *Baculites asper* (?), *Lunatia subcrassa, Tancredia americana, Cardium speciosum, Tellina* (?) sp., and *Mactra.* On the highest points these beds are capped by about 3 feet of impure lignite overlain by light sandy shales with a few *Unios* and turtle fragments. In the marine sandstones underlying these lignites, along with the invertebrates just mentioned, were found several species of sharks' teeth.

Two and a half miles below the police station, in the bluff on the north side of the river, is a bed of well-preserved shells, about 2 feet thick, immediately overlying the 4-foot lignite seam seen in the bluff just below the police station. In this shell bed we collected *Unio subspatulatus, Unio supragibbosus* (?), *Modiola, Corbicula occidentalis, Corbicula cytheriformis* (?), *Corbula subtrigonalis, Corbula perundata, Rhytophorus glaber,* and *Goniobasis invenusta,* all in a good state of preservation. This shell bed is overlain by about 10 feet of arenaceous shale, which is light at the base and dark above, and is followed by a 3-foot vein of lignite.

In a canyon tributary to Milk River about 8 miles below Pendant d'Oreille the following section is shown:

Section in canyon tributary to Milk River 8 miles below Pendant d'Oreille.

	Feet.	Feet.
2. Judith River beds:		
d. Light-colored sandstones and shales with a variable upper member of yellow, cross-bedded, concretionary sandstone which shows a maximum thickness of 100 feet in the upper course of the canyon	300	

	Feet.	Feet.
2. Judith River beds—Continued.		
c. Sandstones, lignites, and shales with several layers of *Ostrea subtrigonalis* and some fresh-water shells. The principal lignite bed, 6 to 8 feet in thickness, is at the base	50	
b. Light-colored sandstones, becoming yellow toward the top	50	
a. Buff arenaceous shales with remains of turtles and fragments of dinosaur bones	25	
		425
1. Marine beds belonging to the Claggett formation, consisting of dark shales with bands and lenticular layers of brown sandstone, containing *Tancredia americana*, *Tellina* (?) sp., and *Vanikoropsis tuomeyana*, with an admixture of such brackish-water forms as *Ostrea glabra*, *Corbula subtrigonalis*, and *Melania ? whitearesi*, about		100

From Pendant d'Oreille to Hooper's ranch, on Many Berries Creek, about 5 miles northwest of Pakowki (Badwater) Lake, the Judith River beds are exposed at frequent intervals in the slopes of the hills a few miles east of the trail. They also appear in the bluffs of the creek both above and below the ranch. Some miles northeast and east of Hooper's ranch there is a high ridge forming the divide between Sage Creek and Many Berries Creek (Big Timber Creek of some maps). Along the western slope of this ridge the Judith River beds are extensively exposed and are overlain by the Bearpaw shales.

SAGE CREEK AREA, ASSINIBOIA.

On Sage Creek, a small stream from the overflow of which Wild Horse Lake has its origin, there are important exposures of the Judith River beds, which have been described and mapped by Mr. R. G. McConnell. These occur north of the lake on the west side of the road, about 8 miles north of the international boundary, and also about 2 miles below Carroll's ranch, on Sage Creek. At the place last named some excellent exposures of the Judith River beds in the bluffs of a western tributary of the creek yielded *Sphærium planum*, *Goniobasis sublævis*, *Viviparus*, and plant fragments, including a cone. The lignite-bearing strata at the top of the Judith River beds are not represented here, but just above Carroll's house, on the west side of the creek, they appear, and they are frequently exposed for several miles in the bluffs of Sage Creek and its tributaries with characteristic vertebrate and invertebrate fossils. About 5 miles above Carroll's ranch and a mile or two above the mouth of the West Fork, Sage Creek flows through a deep, narrow gorge, the hills being much higher on the west side than on the east, and somewhat higher than the plain to the southeast. In the upper part of this bluff are about 50 feet of Bearpaw shales with *Baculites ovatus*, *Placenticeras whitfieldi*, *Callista deweyi*, *Cyprina ovata*, and *Ostrea patina*. Underlying these shales are about 150 feet of the upper Judith River beds, with the lignites at

the top and light ash-colored and brown sandstones at the bottom (see Pl. X, *B*). In a brown sandstone about 10 feet above the creek are *Unios* and other fresh-water invertebrates, and 75 feet above the creek, near the base of 15 feet of light ash-colored sandstones overlying a bed of impure lignite, we found a considerable portion of a *Trachodon* skeleton. (See Pl. X, *A*.)

The following is a section from the bed of the creek to the top of the hill as displayed at this place:

Section on Sage Creek, Assiniboia.

	Feet.
4. Bearpaw shales with characteristic fossils, *Ostrea patina*, *Placenticeras whitfieldi*, and *Baculites ovatus*, etc	50
3. Finely banded shales with 4 feet of impure lignite at base and several feet of same at top. Occasional thin seams of lignite in main body of shales	50
2. Light ash-colored sandstones with *Trachodon* skeleton at base	15
1. Sandstones and shales with lignites, the latter especially well developed toward the top. Ten feet from the base is a heavy bed of hard sandstone, weathering brown, with *Unio danæ*, *Anodonta propatoris*, *Sphærium*, *Physa*, and *Hyalina occidentalis*. In the middle there is an exposure of about 10 feet of light ash-colored sandstones with ferruginous nodules and lenses of brown sandstones. The nodules have numerous fragmentary plant remains. This is overlain by 15 feet of arenaceous shales and lignites	75

About 4 miles farther up Sage Creek, in the vicinity of McClean's ranch, are important exposures of the Bearpaw shales with such characteristic fossils as *Baculites ovatus*, *Placenticeras whitfieldi*, *Ostrea patina*, and *Inoceramus sagensis*. This is a typical development of the Bearpaw shales, consisting of dark, finely laminated shales with limestone nodules inclosing numerous specimens of *Baculites* and *Placenticeras*. These shales are clearly seen to be the same as those overlying the Judith River beds farther down the creek. The aneroid gave them a thickness of 110 feet, but the base was not shown. On the west side of the creek, a mile below McClean's fence, there is a small exposure of the Judith River beds just at the bottom of the creek bluff. This is the uppermost member of these beds, the main body having here passed beneath the level of the stream. About 65 feet of the uppermost lignitiferous beds are represented.

Opposite McClean's ranch, on the south side of Sage Creek, 100 feet of upper Judith River beds overlain by 200 feet of Bearpaw shales form a range of hills 3 miles west of south of McClean's house. The Bearpaw shales at this locality yielded *Baculites ovatus*, *B. compressus*, *Placenticeras whitfieldi*, *P. intercalare*, *Nautilus dekayi*, *Ostrea patina*, *Cyprina ovata*, *Callista deweyi*, gasteropods, and crustaceans. No fossils were found in the Judith River beds, which here consist of the uppermost 100 feet of that formation and carry much impure lignite. The Bearpaw shales are here cut by two or three sandstone dikes, each

A. EXPOSURE OF JUDITH RIVER BEDS ON SAGE CREEK, ASSINIBOIA.

Showing remains of Trachodon skeleton.

B. CONTACT BETWEEN JUDITH RIVER BEDS AND OVERLYING BEARPAW SHALES ON SAGE CREEK, ASSINIBOIA.

about 10 inches wide and several hundred yards in length. These dikes have a northwest-southeast direction and dip 60° NE. At this locality the Bearpaw shales are very fossiliferous and present four distinct white alkali bands. From this point northward the divide between Sage Creek and Willow Creek, along the road to the Cypress Hills, consists of Bearpaw shales covered by a thin veneer of glacial drift.

On Willow Creek, a small stream rising in the western end of the Cypress Hills, are extensive exposures of Bearpaw shales containing *Baculites compressus*, *Anchura americana*, *Cinulia concinna*, *Lucina subundata*, *Pecten* (*Chlamys*) *nebrascensis*, and *Avicula linguiformis*. Just below John Reed's ranch, on Willow Creek, a heavy bed of brown sandstone caps these shales. In no place in this vicinity were we able to find the base of the shales exposed, so that we were unable to estimate their thickness. As one ascends Willow Creek the brown sandstones mentioned above rapidly increase in prominence and at the head of the creek form the greater portion of the western extremity of the Cypress Hills. They constitute the highest marine horizon seen in the Cretaceous of this region and on account of their stratigraphic position and lithologic features are comparable with the Fox Hills sandstones of South Dakota. We collected from them a considerable number of marine invertebrates, including *Leda* (*Yoldia*) *evansi*, *Avicula nebrascana*, *Protocardia borealis*, *Tancredia americana*, *Callista nebrascensis*, and *Scaphites nodosus* var. *quadrangularis*. Part of these species are known from the Fox Hills beds in other regions, and most of them occur also in the Pierre and Bearpaw shales. It has long been known that the faunas of the Fox Hills and Fort Pierre are too closely related to be considered really distinct.

Toward the summit of the Cypress Hills, on the western end, are about 60 feet of soft, light-colored, yellow sandstones with a 6-foot vein of lignite near the base. These beds may belong to the Laramie as it has been mapped by McConnell, although we were unable to find any fossils in them by which to determine their age.

The exposures examined by us in Canada are all in the southeastern portion of the large, continuous area of Belly River beds mapped by Dawson, McConnell, and Tyrrell. They include both the top and the bottom of the formation, as well as good exposures of the overlying and underlying beds, and hence give a fair idea of the formation as described by Dawson. The principal localities that have yielded the Belly River vertebrate fossils described by Lambe are on Red Deer River some distance north of the most northern point visited by us, but we have no doubt that they are on the same horizons that we studied.

WILLOW CREEK AREA, IN CENTRAL MONTANA.

In addition to the above-described exposures of the Judith River beds in northern Montana and southern Canada, there are others in central Montana, first observed by Hatcher in 1888. One of these occurs between Musselshell River and Flatwillow Creek. Near Flatwillow post-office a conspicuous ledge of yellow sandstone forms an almost continuous and in places perpendicular wall, extending for miles up and down the south side of the creek. These sandstones weather into pyramid-like forms, dip gently to the southeast, and form the roadbed for about 2 miles along the old freight road from Fort Maginnis to Junction City, where they pass beneath the Claggett formation. In weathering, color, and lithologic character these sandstones resemble the brown phase of the Eagle formation as developed at the type locality at the mouth of Eagle Creek on Missouri River, about 20 miles above the mouth of Judith River. Their stratigraphic position between the Benton and Claggett formations also favors this correlation. Some obscure fragments of *Baculites* were the only fossils yielded by them.

After passing over these sandstones, which have an estimated total thickness of 200 feet, the Claggett formation is reached where the road crosses the first coulee, 2½ miles south of Flatwillow. The Claggett overlies the Eagle sandstones and dips gently to the southeast. The shales of this formation yielded *Baculites* sp., *B. ovatus*, *Placenticeras* sp., *Inoceramus barabini*, *Lucina occidentalis*, and *Nucula*. Both species of *Baculites* were very abundant. Other fossils were rare. About 10 miles from Flatwillow the road crosses a broad, deep coulee which occupies the trough of a wide synclinal fold, and in the bottom of which may be seen considerable exposures of the lower 100 feet of the Judith River beds resting upon the Claggett formation. From the Judith River beds at this point we collected remains of turtles and dinosaurs, and saw a number of more or less fragmentary bones and much petrified wood.

For a mile or more the road crosses the trough of this syncline, and there are beautiful exposures of the Judith River beds on either side. It then once more traverses the shales of the Claggett formation for 7 miles, or until Willow Creek is reached. From the higher points along the road the Eagle sandstones appear in prominent bluffs on the right at a distance of several miles. In this locality the Claggett formation can scarcely have a thickness of less than 500 feet. At Nolan and Archer's ranch, on Willow Creek about 10 miles north of Musselshell River, the Judith River beds again rest on the shales of the Claggett formation, and a series of exposures on the south side of the creek form a low, broken wall. The beds have a slight dip (2° or 3°) southeastward, and consist of light-colored argillaceous sandstones

and sandy clays with occasional lenses and masses of hard brown or gray sandstone. The sandstones are nearly all strongly cross-bedded. The rocks are weathered into typical badland forms and have a thickness of 75 to 100 feet in the principal bluffs and buttes. (See Pl. XI, *A*.) There are some lower beds not so well exposed, as well as higher strata to the southeast that are usually covered, but it is probable that the total thickness of Judith River beds does not exceed 200 feet. Vertebrate remains are common in almost every exposure. Silicified wood is common also, and at one point about a mile east of the wagon road a local deposit of well-preserved plants was found, from which all the plants credited to Willow Creek and described by Dr. F. H. Knowlton in this paper were obtained. These plants were all collected in an area of 3 or 4 square yards, from a bed about 1 foot in thickness. About 2 feet below the plants in the same exposure the femur, tibia, and fibula of a large *Trachodon* were obtained. Half a mile east of this locality and on about the same horizon fresh-water Mollusca are common, including *Goniobasis sublævis*, *Anodonta propatoris*, *Sphærium*, and three or four species of *Unio*.

West of the wagon-road crossing of Willow Creek the strata immediately underlying the Judith River beds are scarcely at all exposed, but about 6 miles west of the road there are conspicuous bluffs of light brownish or yellowish sandstone, dipping 5° or 6° NE., that probably belongs to the Eagle formation. South of the creek is a line of cliffs several miles long that often show vertical exposures 75 feet in height. At the base of the cliffs there are small exposures of dark shales, like the Benton, near the top of which an imperfect specimen of *Placenticeras* was collected. The overlying sandstones are exposed to a thickness of about 100 feet, and after a covered interval of 50 feet these are succeeded by 15 feet of similar sandstone. In the lower 25 feet these sandstones are strongly cross-bedded and weather into large, rounded masses. These are succeeded by 50 feet of more massive sandstone, overlain by 25 feet of thicker bedded sandstone. Fossils are rare except in occasional nodules, some of which yield numerous specimens. Near the base of the formation we collected *Pecten*, *Avicula linguiformis*, *Nucula*, *Lucina subundata*, *Cinulia*, *Nautilus dekayi* (?), *Scaphites* related to *S. hippocrepis*, and young individuals of a small, slender *Baculites* that occurs in the Eagle formation on the Missouri. About 75 feet higher specimens of *Inoceramus*, related to *I. fragilis*, were obtained.

About 2 miles east of the road, in a bend of the creek, is a good exposure showing the contact of the Judith River beds with the Claggett formation. In a distance of about 5 miles along the road from Willow Creek to Musselshell post-office there is obtained a complete section from the base of the Judith River beds up through the Bear-paw shales into the overlying formations, which latter we did not study

in detail. All the beds dip gently to the southeast. The dip increases in the upper part of the section, being greater in the upper Bearpaw shales than in the Judith River beds, which are here clearly seen to pass beneath the Bearpaw shales. These shales, especially the upper portion, are rich in marine invertebrates, including the following species:

Fossils obtained from Bearpaw shales near Musselshell post-office.

Ostrea pellucida.
Syncyclonema rigida.
Pecten (Chlamys) nebrascensis.
Avicula nebrascana.
Avicula linguiformis.
Inoceramus barabini.
Nucula subplana (?).
Nucula planimarginata (?).
Nucula cancellata (?).
Leda (Yoldia) evansi.
Trigonarca exigua.
Lucina subundata.
Protocardia rara.
Cuspidaria ventricosa.
Liopistha (Cymella) undata.
Thetis? circularis.
Anchura americana.
Acmæa occidentalis.
Vanikoro ambigua.
Lunatia occidentalis (?)
Haminea subcylindrica.
Cinulia concinna.
Baculites compressus.
Baculites ovatus.
Scaphites nodosus var. brevis.
Placenticeras whitfieldi.
Placenticeras intercalare.

Immediately above the Bearpaw shales is a very thick series of sandstones with intercalated shales and occasional lignite beds, which we were unable to study in the limited time at our disposal, though we made a brief fruitless search for fossils in the lower portion. At the base the dip is 15° to 20° to the south, and higher in the section it increases to 30° or more, these tilted beds forming a belt about 2 miles in width and consequently several thousand feet thick. From a point about 2 miles north of Musselshell post-office southward to Musselshell River similar beds occur with very low dips, and we saw such exposures of the same formation for many miles along the Musselshell above the post-office. The only paleontologic evidence of the age of the formation overlying the Bearpaw shales in this region was found at two localities about 14 and 17 miles west of Musselshell post-office, where we obtained a few plants from a horizon probably high in the section. Doctor Knowlton has identified among them *Taxodium occidentalis* Newberry, *Populus speciosa* Ward, *Populus* related to *P. cuneata* Newberry, *Platanus*, *Ulmus rhamnifolia?* Ward, *Sapindus grandifolius?* Ward, *Cocculus haydenianus* Ward. Concerning them he says: "These species are typically Fort Union and I do not hesitate to refer them to this horizon."

The beds between this horizon and the top of the Bearpaw shales should, from their stratigraphic position, contain the equivalent of the Fox Hills and the Laramie as well as the Livingston formation, which was described by Weed in the Crazy Mountains, less than 100 miles to the west.

A. JUDITH RIVER BEDS ON WILLOW CREEK 10 MILES NORTH OF MUSSELSHELL, MONT.

B JUDITH RIVER BEDS ON FISH CREEK, MONT.

FISH CREEK AREA.

There is a considerable exposure of the Judith River beds between Fish Creek and Mud Creek, small tributaries of Musselshell River near Melville, Mont., a few miles northeast of the Crazy Mountains. These exposures were first discovered by Mr. Earl Douglass and were described by him under the name of the Fish Creek beds, with the suggestion that they are the probable equivalents of the Belly River beds. Not being familiar with the Judith River beds, Mr. Douglass was unable to recognize the identity of the Fish Creek and Judith River outcrops. In their stratigraphic position as well as in their lithologic and faunal characters they are almost identical with the Judith River beds farther north and should be referred to that formation.

These beds are best exposed on Crawford's ranch between Fish and Mud creeks, where they occur in a typical badland region of limited extent. (See Pl. XI, *B*.) Throughout most of this area the Judith River beds have a very gentle southerly dip. This is especially true on the slope looking toward Fish Creek, but at the divide between Fish and Mud creeks the beds are faulted, the fault running irregularly in an east-west direction. Immediately south of this fault the Judith River beds are nearly horizontal, while to the north they are much inclined, in places being nearly vertical or dipping southwesterly at angles varying from 30° upward, so that they appear to be unconformable with and to pass beneath the Judith River beds to the south of the fault. The upper part of the disturbed series is clearly Judith River, and it is evident that the strata have been faulted and that the unconformity is only apparent. To the south and west of this badland area the Judith River beds are overlain by Bearpaw shales bearing the same fauna that has been listed from Willow Creek and other localities. These have an aggregate thickness of several hundred feet and occupy most of the region to the west between the two creeks. South and west of Fish Creek these shales are overlain by marine Cretaceous sandstones and by a thick series of beds that have been referred to the Laramie, Livingston, and Fort Union formations. The Judith River beds in this region are very similar to those on Willow Creek, Dog Creek, and the Missouri at and below the mouth of Judith River. They contain remains of *Trachodon*, *Ceratops*, turtles, and crocodiles of Judith River types in fair abundance, much petrified wood, and beds of fresh-water Mollusca. The beds are usually light ash-colored sands and sandy shales with frequent bands of impure lignite and black ferruginous concretions. In a small draw or canyon running west by north from the badlands to Mud Creek (the draw in

which the Crawfords get their coal) the following section is exposed, commencing at the fault mentioned above and going down the draw:

Section in small draw north of Mud Creek.

	Feet.
4. Lower Judith River beds	200?
3. Claggett beds (sandstones and shales with *Inoceramus* and *Baculites*)	300?
2. Eagle sandstones and shales, with thick bed of coal 100 feet from the base	400?
1. Benton shales, base not exposed	300?

The above thicknesses are mere guesses and can not be considered even as an estimate. No. 3 is probably much below the actual thickness.

The Claggett beds are here made up very largely of sandstones, though there are several beds of shales which are usually poorly exposed.

The Eagle sandstones present the usual characters of that formation, and the lignite is especially good.

The passage from the Eagle to the Claggett formation and from the Claggett to the Judith River beds is so gradual that it is difficult to say where the one commences and the other ends. The Bearpaw shales are well differentiated from the underlying Judith River beds, and the line of demarcation between the Benton and the Eagle formations is likewise very distinct. Northward down the draw toward Mud Creek the dip of the Benton gradually decreases and a few calcareous and ferruginous nodular layers are seen here and there, always more or less fossiliferous with *Scaphites ventricosus*, *Baculites asper* (?), *Inoceramus umbonatus*, *I. exogyroides*, and *Pholadomya papyracea*.

The influence of the various horizons on the topography is marked. South and southwest of Widdecombe Creek, a branch of Fish Creek, the alternating sandstones and shales of the formations overlying the Bearpaw have produced a rugged topography characterized by a series of low sawtooth ridges of harder sandstones, separated by gentle valleys occupied by the intervening beds of shales and other soft material. Between this creek and the Crawford badlands there is an area of low rolling hills about 6 miles wide that is composed of weathered Bearpaw shales. Northward, in the area of the Judith River, Claggett, and Eagle beds, is another series of rugged ridges separated by narrow valleys. Still farther north is a low rolling country which extends northward to and beyond Musselshell River and which is the result of the erosion and weathering of the Benton shales.

Two miles west of the small draw mentioned above, where Mud Creek has cut its way through the upturned beds of the Judith River, Claggett, and Eagle formations, a fairly good section is shown from the Bearpaw shales down through the above-mentioned formations into the Benton. Through most of this section the beds are inclined to the northwest at an angle of about 60°.

OTHER PROBABLE AREAS.

Along Milk River the Judith River formation is known to extend far east of Havre, where we studied it. Its limits in that direction have not been determined. It is very probable that this area is connected with the Cow Creek area by almost continuous exposures across the divide separating the drainage of the Missouri from that of Milk River east of the Bearpaw Mountains. On our journey from Havre to Cow Creek we passed through the eastern foothills of these mountains and crossed several areas of igneous rocks, but on Bean Creek near Lloyd post-office we saw outcrops apparently belonging to the Judith River beds, and if our route had been a few miles farther east we could probably have had the formation in sight all the time.

A few miles north of Billings, on the road from Roundup post-office on the Musselshell to Billings, Mont., we noticed outcrops that almost certainly belong to the Judith River formation. This area is along the line of a section described by Lindgren in volume 15 of the Tenth Census and was referred by him to the Laramie.

About 50 miles farther east on the Yellowstone, near the mouth of Bighorn River, Hayden has described exposures that may also belong to the Judith River formation.

There are certainly other areas of Judith River beds in the valley of Musselshell River north and west of the Fish Creek area which we have described. One of these is indicated by Lindgren's [a] description of the occurrence of marine Cretaceous above so-called Laramie beds near the mouth of Swimming Woman Creek. Another of these probable areas is indicated by the reported occurrence of Judith River species of brackish-water Mollusca at a locality north of the Crazy Mountains, where the beds containing them were referred by Weed[b] to the Livingston formation.

In this connection attention may be called to the occurrence of non-marine coal-bearing beds within the Montana group at Coalville, Utah, at Point of Rocks, Wyo., and at several points on the Laramie Plains, southern Wyoming.[c] These beds are probably not very far from the horizon of the Judith River beds, but it is not believed that the facts would justify their reference to that formation.

[a] Tenth Census U. S., vol. 15, p. 743.

[b] Bull. U. S. Geol. Survey No. 105, p. 33.

[c] See Stanton and Knowlton, Stratigraphy and paleontology of the Laramie and related formations in Wyoming: Bull. Geol. Soc. America, vol. 8, pp. 127–156.

RÉSUMÉ AND CONCLUSIONS.

Our field studies in the original Judith River area have established the stratigraphic succession of the Upper Cretaceous section and show that the Judith River beds lie beneath several hundred feet of marine Cretaceous shales with a characteristic invertebrate fauna, and that they rest upon another marine formation which also bears an abundant fauna. The overlying formation we have called the Bearpaw shales, because it is well exposed in the area south, east, and north of the Bearpaw Mountains. The name Claggett formation has been given to the underlying beds because they are well developed around the site of old Fort Claggett, near the mouth of Judith River. Wherever the exposures in this region show lower beds the lignite and conspicuous sandstone ledges of the Eagle formation are seen, and still lower the dark Benton shales with a characteristic fauna are revealed. The Judith River formation itself has yielded a fauna of both vertebrates and invertebrates, most of which are peculiar to it. Its lithologic features also are different from those of any other formation in the section and make it easily recognizable.

Beyond the typical area, we found on Milk River in the neighborhood of Havre a similar succession of formations from the Claggett to the Bearpaw, inclusive. The formation occupying the position of the Judith River beds here has the same lithologic and paleontologic characteristics as in the original area, with which it probably has direct connections around the east end of the Bearpaw Mountains. It is therefore unhesitatingly identified with the Judith River beds. From Havre this formation was traced by means of practically continuous exposures and without essential change of lithologic and paleontologic characters into an area of Belly River beds mapped by Dawson. Here again the underlying Claggett formation was recognized by its fossils and lithologic features, and above the Judith River (Belly River) beds the Pierre shales of the Canadian geologists are clearly identical with the Bearpaw shales of our Montana section.

In other areas studied by us in Montana the same succession of formations was observed. Two horizons in this region are especially well characterized by marine invertebrates—one in the upper part of the Benton shales and the other in the Bearpaw shales. Wherever these were both present in one section the succession and recognition of the intervening formations were unmistakable.

The stratigraphic relations are more clearly shown in the following diagrammatic arrangement of comparative sections:

Sections in South Dakota, Montana, and Assiniboia.

	South Dakota section.	Central and northern Montana section.	Southern Assiniboia section.
	Laramie.	Laramie?	Laramie?
	Fox Hills.	Fox Hills?	Fox Hills?
Montana group.	Pierre.	Bearpaw.	Bearpaw.
		Judith River.	Belly River (Judith River).
		Claggett.	Claggett.
		Eagle.	(?)
Colorado group.	Niobrara.		
	Benton.	Benton.	(?)
	Dakota.	Dakota?	(?)

The Montana and Colorado groups are generally recognized as larger subdivisions of the strata lying between the Dakota and the Laramie. The South Dakota and Nebraska section is the Meek and Hayden section with the Laramie added, while the other two columns represent the sections studied by us. The queries in the lower part of the columns indicate formations not seen by us in the regions mentioned, and the queries in the upper part of the column indicate our doubts as to the correlation of any particular horizon in these sections with the Fox Hills, and as to the limits of the Laramie and its relationship with overlying formations that have been described in the region.

A few words of explanation are necessary concerning the general correlations expressed and the introduction of new formation names. In the first place, the entire Upper Cretaceous section as described by Meek and Hayden along Missouri River in South Dakota and Nebraska is very much thinner than the Montana section, and in some portions the lithologic development is not at all similar. Consequently the comparison of individual formations or horizons is in several cases made difficult.

Beginning the examination at the base of the section and leaving the Dakota out of consideration at present, the first difficulty is in connection with the Benton, especially as to its upper limits. In the upper Missouri section near Fort Benton a continuous body of shales extends up to the base of the Eagle sandstone, and so far as is now known there is no lithologic basis for a division in it. There are,

however, two well-marked faunal zones—a lower one characterized by *Inoceramus labiatus*, *Scaphites warreni*, and the keeled ammonite genera *Prionotropis* and *Prionocyclus*, and an upper zone with *Inoceramus umbonatus*, *Inoceramus exogyroides*, and *Scaphites ventricosus*. In the section farther east in South Dakota and Nebraska the shales referred to the Benton are limited above by the Niobrara limestone, and their fauna corresponds closely to that of the lower zone above mentioned. If it is assumed that the upper limit of the Benton shales in the two sections is identical, and that the sequence upward is continuous in both cases, then it must follow that the Eagle sandstone is or includes the equivalent of the Niobrara limestone, and should be correlated with it, though, of course, distinctive formation names are necessary. But all the paleontologic evidence is opposed to their correlation. On the one hand, the fauna in the upper Benton zone of the western section has its nearest representative in Colorado and Texas in beds that are referable to the upper Niobrara, and on the other hand the fauna of the Eagle formation is much more closely allied to the fauna of the overlying marine formations than to the Benton fauna, and consequently the formation belongs to the Montana rather than to the Colorado group. The objection may be raised that the Eagle is a littoral formation, and that its fauna would therefore be different from the Niobrara faunas, but there are littoral faunas known at the top of the Benton in Colorado, northern Utah, and southwestern Wyoming, and these are wholly different from the Eagle fauna. The most reasonable view seems to be that the Fort Benton of the western section includes the representatives of both the so-called Fort Benton and the Niobrara of the eastern section.

The second serious difficulty in the Montana section is in determining the exact equivalent of the Pierre shales. This formation was named from Fort Pierre on the Missouri, now Pierre, S. Dak., and was defined as dark clays, limited above by the Fox Hills sandstone and below by the Niobrara limestone, with exposures along the Missouri for some distance both above and below Fort Pierre. Meek and Hayden's estimate of the thickness was 700 feet, but more recent estimates by Darton in the same general region place it at 1,200 to 2,000 feet. It contains a large and characteristic invertebrate fauna. In the Montana section the shales we have called Bearpaw shales are very similar to the Pierre in lithologic character, and they bear a fauna composed in the main of identical species, showing an assemblage especially similar to that of the upper fossiliferous zone of the Pierre. The thickness possibly also approaches that of the Pierre in the typical area.

That the Bearpaw shales represent a part of the Pierre is unquestionable, but if they are strictly equivalent to the Pierre, so that they should be called by the same name, then in the South Dakota section

there is a long unrepresented interval between the Niobrara and the Pierre, for, as we have shown, there is considerable evidence that the Eagle formation is later than the Niobrara. The overlying Claggett and Judith River formations certainly come within the Montana group. It is true that Meek and Hayden observed some evidences of erosion at the top of the Niobrara, but it does not seem probable that erosion or nondeposition could have continued throughout the time represented by the three formations just named without showing greater effects than have been observed. It is well known that along the western margin of the Great Plains in Colorado there is a great thickening of the Pierre, or at least of the formation in the corresponding position, so that in the Denver region it attains the thickness of 7,000 feet, while farther south, in the Arkansas Valley, its thickness is over 4,000 feet. Although in all this great thickness several zones have been more or less clearly recognized by minor differences in the fauna and in lithologic features, no basis for separation into distinct formations has been found. In the Montana section the shaly portion of the Claggett formation does not differ very greatly in lithologic character from the Bearpaw shales, and though the fossils are less numerous they are all of species that occur in the Bearpaw and the Pierre, while the sandstone members of the Claggett bear a littoral fauna that is closely related to that of the Fox Hills and even contains many of the same species. It is very probable, therefore, that the Claggett would not have been separated from the Bearpaw as a distinct formation if the totally different Judith River beds had not been interpolated between them, for the intermingling of Fox Hills and Pierre species has long been known elsewhere.

In view of the facts above stated it seemed expedient to give the local name Bearpaw shales to the formation immediately overlying the Judith River beds, rather than to regard it as the strict equivalent of the Pierre and to call it by that name, although we do not doubt that the one formation can be traced directly into the other and that some zones in both are identical. The Claggett formation is a stratigraphic unit, distinct and easily separable from the previously defined formations above and below it, and hence it required a new name.

Returning to the correlation diagram (p. 63), we wish to leave the question open whether the Pierre fills *all* of the space corresponding to that occupied by the Bearpaw, Judith River, Claggett, and Eagle formations, although we are confident that all of these belong to the Montana group. The identification of the Fox Hills formation in the Montana section is left in doubt partly because we did no detail work on that part of the section, and more especially because we have found that many of the Fox Hills species have a great vertical range, throughout which they may be expected to occur wherever suitable

conditions are found, so that paleontologic identification of the formation without the most careful stratigraphic work is extremely unreliable. The problem of the Laramie and associated later formations in this region is a very complex one, to which we were able to devote very little time, and consequently we do not desire to express any definite opinions concerning it.

Our principal conclusions from the season's work may be summarized as follows:

1. The Judith River beds are distinctly older than the Laramie, being separated from the latter by at least several hundred feet of marine shales identical in their faunal and lithologic features with the Pierre to which we have given the local name Bearpaw shales, from the Bearpaw Mountains about which they are well exposed.

2. The Belly River beds of Canada are identical with the Judith River beds of Montana. The name Judith River beds, having priority, should be the accepted name for this formation and the terms Belly River and Fish Creek beds should be dropped.

3. The marine sandstones and shales immediately underlying the Judith River beds do not represent either the Benton, as some Canadian geologists have supposed, or the Fox Hills and upper Pierre, as most geologists of the United States who have examined them have believed, but they constitute a distinct horizon within the Montana group which we have called the Claggett formation, from old Fort Claggett at the mouth of Judith River, near which they are well developed.

4. The Eagle formation, from its stratigraphic position and faunal relations, marks the base of the Montana group in this region.

5. The Bearpaw shales, the Judith River beds, the Claggett and the Eagle formations all belong to the Montana group, and together probably form the equivalent of the Pierre as that term is generally understood, though the possibility is recognized that in the typical area the Pierre may have more restricted limits.

6. Faunas similar to that of the Fox Hills sandstone have a great vertical range and are likely to be found at any horizon within the Montana group where a littoral or shallow-water facies is developed. The use of the term Fox Hills as a formation or horizon name outside of the original area in South Dakota is therefore of doubtful propriety, as experience has shown.

VERTEBRATE FAUNA.

By J. B. HATCHER.

Leidy, Cope, Marsh, Osborn, and Lambe have been the chief contributors to our knowledge of the vertebrate fauna of the Judith River beds. A considerable number of genera and species pertaining to all five of the known classes of vertebrates have been described. Unfortunately these genera and species are for the most part based on exceedingly fragmentary and unsatisfactory material, and it has been quite impossible to determine with accuracy even the principal osteological or dental characters of most of the genera or to compare them intelligently with related forms from older or more recent formations. As an aid to future students there is given here a list of the various genera and species of vertebrates that have been described by various authors, with a reference to the original description and a brief statement concerning the nature of the types upon which they were based.

PISCES.

Altogether six genera and eight species of fish have been described from deposits referred by us to the Judith River beds. These genera and species are known only from detached scales, teeth, and bones. They doubtless represent only a small fraction of the fish fauna of these beds. While they give an indication of the character of some of the fishes that inhabited the waters of this region in Judith River times, they are at present known from such insufficient material as to render them of little value for purposes of correlation, as is abundantly evidenced by the apparent similarity existing between the fish remains known from these beds and those from the Laramie. This similarity is so striking that some paleontologists have been led, largely from such evidence, to correlate the Judith River beds with the Laramie, disregarding the more important evidence afforded by the dinosaurian fauna and the stratigraphy.

LEPIDOTUS OCCIDENTALIS Leidy.

Lepidotus occidentalis Leidy, 1856, Proc. Acad. Nat. Sci. Philadelphia, 1856, p. 73.

Leidy described the species as follows:

A species proposed on five specimens of thick lozenge-shaped scales, with the root prolonged in the direction of the long diameter. The enameled surface of the scales is smooth and shining. The largest one has its sides about 4 lines long, the smallest one about 2½ lines long.

LEPIDOTUS HAYDENI Leidy.

Lepidotus haydeni Leidy, 1856, Proc. Acad. Nat. Sci. Philadelphia, 1856, p. 73.

The original description of the species was as follows:

A species proposed on a single specimen of a thick oblong square scale, the long sides of which measure 5 lines and the short 3½ lines. The root projects forward from one of the long sides, and the enameled surface of the scales is covered with parallel square lines.

CERATODUS ERUCIFERUS Cope.

Ceratodus eruciferus Cope, 1876, Proc. Acad. Nat. Sci. Philadelphia, 1876, p. 259.

This species was described by Cope as follows:

A basal lamina separable from the dentigerous lamina. The latter supports ribs which diverge from a single marginal rib which extends along one side. The marginal rib is separated by a deep groove from the radiating ribs, which is continuous with the grooves between the latter. The ribs are of irregular diameter and not perfectly straight; they are interrupted by weak transverse ridges, which project beyond the margin. The ridges rise abruptly from their common base and are separated distally by notches of the margin.

Measurements.

	M.
Long diameter of dental surface	0.011
Short diameter of dental surface	.007
Thickness of plate	.003

There are six ridges in the length.

CERATODUS HIEROGLYPHUS Cope.

Ceratodus hieroglyphus Cope, 1876, Proc. Acad. Nat. Sci. Philadelphia, 1876, p. 260.

This species was described by Cope as follows:

The dentigerous plate is thin and dense, and has the appearance of a short-toothed comb with a handle. The tooth-like points are the extremities of low ridges, which are arranged nearly at right angles to a wide longitudinal elevated half of the osseous base. They are separated by shallow grooves from each other, and are not continuous with the basis just mentioned, which rises abruptly above them. They are smooth. The "handle" above alluded to is triangular in section, having two bevels on the side supporting the tooth ridges. The lower face of the bone is smooth.

Measurements.

	M.
Total length	0.013
Length of dentigerous portion	.010
Total width	.0045
Width of dentigerous portion	.0020

There are thirteen teeth in the length.

MYLEDAPHUS BIPARTITUS Cope.

Myledaphus bipartitus Cope, 1876, Proc. Acad. Nat. Sci. Philadelphia, 1876, p. 260.

This species is founded on detached and isolated teeth. Teeth of this pattern and of varying size are abundant both in the Judith River beds and in the Laramie. It would be quite impossible to identify either genera or species from teeth of such simple form.

HEDRONCHUS STERNBERGII Cope.

Hedronchus sternbergii Cope, 1876, Proc. Acad. Nat. Sci. Philadelphia, 1876, p. 259.

Cope described this species as follows:

Char. Gen.—The bone on which this genus reposes has the appearance of the crown of a young tooth. Its central cavity is large and expands to the margin of the basis; its apex is unworn. It appears to be too protuberant for the position of a dermal tubercle. It may be distinguished as a short crown on a shorter slightly constricted portion or neck. The crown culminates in three crests, which together form a letter T, and which descends toward the neck. There is no investment of cement or enamel, and the material of which it is composed resembles dense bone.

Char. Specif.—The faces on each side of the stem of the T are concave and divided by an oblique crest, which descends from the common apex. The other face is gently convex, and the inferior part of each of its bounding crests projects ear-like. The base is an oval.

Measurements.

		M.
Elevation of crown		0.006
Diameter of base	longitudinal	.005
	transverse	.004

ACIPENSER ALBERTENSIS Lambe.

Acipenser albertensis Lambe, 1902, Cont. Canadian Palæont, vol. 3, pt. 2, p. 29.

This species is founded on a detached keeled dermal shield from the Judith River beds of Red Deer River, Canada. Similar ossifications are common in the Judith River beds and in the Laramie of Converse County, Wyo., and probably represent more than one species.

DIPHYODUS LONGIROSTRIS Lambe.

Diphyodus longirostris Lambe, 1902, Cont. Canadian Palæont, vol. 3, pt. 2, p. 30.

This species is founded on a jaw fragment from the Judith River beds of Canada, with numerous tooth scars which show the teeth to have been simple and conical and ankylosed with the jaw. Fragments of similar jaws are common both in the Judith River beds of Montana and in the Laramie deposits of Converse County, Wyo.

AMPHIBIA.

Two genera and five species of tailed Batrachia have been described from the Judith River beds. All of these have been founded on very fragmentary and insufficient material, consisting for the most part of detached vertebræ, with an occasional limb bone or jaw fragment. Similar remains, for the most part undescribed, are common also in the Laramie.

All five of the species of Batrachia mentioned were described by Cope from material secured in the Judith River beds of Montana. Lambe[a] has reported *Scapherpeton tectum* Cope from the same beds on

[a] Cont. Canadian Palæont., vol. 3, pt. 2, p. 31.

Red Deer River in Canada. From the fragmentary nature of the types on which were based Cope's descriptions of the various genera and species, it will readily appear how extremely difficult it will be to refer any material with certainty to any of his species. Moreover, the fragmentary nature of all the remains of Batrachia thus far recovered from this formation renders them of little value for purposes of correlation, and were these remains better preserved it is improbable that they would afford any very reliable evidence as to the exact or relative age of the deposits, owing to the apparently slight modification which has taken place in these Batrachia throughout Cretaceous and Tertiary times. The Batracia of the Judith River beds can not be regarded as of any special value in determining the age of the deposits or in correlating them with other formations.

SCAPHERPETON Cope.

Scapherpeton Cope, 1876, Proc. Acad. Nat. Sci. Philadelphia, 1876, p. 353.

This genus was described by Cope as follows:

Vertebræ deeply biconcave, with opposed, but not continuous, foramina for the chorda dorsalis. Neural arch with zygapophyses, and well-developed neural spine. Centrum with vertically compressed, short diapophysis near the posterior extremity, a prominent hypapophysial keel, and prolonged neural spine. Supposed proximal limb bone with a branch-like trochanter. Supposed teeth in several rows, attached in shallow alveoli, those of the marginal series larger; the crowns obtusely conic and simple.

SCAPHERPETON TECTUM Cope.

Scapherpeton tectum Cope, 1876, Proc. Acad. Nat. Sci. Philadelphia, 1876, p. 355.

This species is founded on a single vertebra accompanied by a fragment which, according to Cope, "resembles the articular portion of the mandible."

SCAPHERPETON LATICOLLE Cope.

Scapherpeton laticolle Cope, 1876, Proc. Acad. Nat. Sci. Philadelphia, 1876, p. 356.

This species was founded on an atlas and several dorsal vertebræ of different individuals, which latter, according to the author of the species, may pertain to the preceding species. An imperfect limb bone was found associated with the neural arch of a vertebra of the character ascribed to this species, and was described by Cope in connection with the type.

SCAPHERPETON EXCISUM Cope.

Scapherpeton excisum Cope, 1876, Proc. Acad. Nat. Sci. Philadelphia, 1876, p. 357.

This species was founded on scattered vertebræ from three individuals of different sizes.

SCAPHERPETON FAVOSUM Cope.

Scapherpeton favosum Cope, 1876, Proc. Acad. Nat. Sci. Philadelphia, 1876, p. 357.

This species is founded on a single vertebra.

HEMITRYPUS JORDANIANUS Cope.

Hemitrypus jordanianus Cope, 1876, Proc. Acad. Nat. Sci. Philadelphia, 1876, p. 358.

This genus and species were founded on a single vertebra from the Judith River beds. This genus is distinguished from the preceding genus by the position of the foramen chordæ dorsalis.

REPTILIA.

The Reptilia are far better represented in the Judith River beds than the other classes of Vertebrata. Not only are most of the larger subdivisions of the group represented, but the fauna is rich also in genera and species which in Judith River times were evidently undergoing a rather rapid development and acquiring a considerable degree of specialization. Genera and species such as these, which may be termed progressive types, afford the most reliable paleontological evidences upon which to base accurate correlations. The more specialized Reptilia offer more trustworthy evidence as to the age of these beds than any other group of vertebrates. Furthermore, from the abundance and condition of the remains the reptilian fauna of this formation and of other formations can be more carefully compared than is practicable with other classes of vertebrates.

PLESIOSAURIA.

While the Judith River beds are for the most part of fresh- and brackish-water origin, it is evident that at certain periods during their deposition the sea had access to limited areas of the region over which these beds are distributed. At certain localities like that mentioned on page 42, remains of typically marine invertebrates and vertebrates occur well within the limits of the Judith River beds. From such marine deposits we obtained shark's teeth pertaining to a number of distinct species, and remains of plesiosaurs and chelonians, some of which latter appear also to belong to marine species.

CIMOLIASAURUS MAGNUS Leidy.

Cimoliasaurus magnus Leidy, 1853, Proc. Acad. Nat. Sci. Philadelphia, 1853, p. 325. Smithsonian Contrb. to Knowl., vol. 14, p. 25.

Lambe[a] has reported vertebræ pertaining to this genus and species from the Judith River beds of the Red Deer River, Canada. The original description of this genus and species was based on vertebræ from the Greensands of New Jersey, for the most part of much larger size than those described by Lambe, and it is not improbable that the material described by the latter may pertain to a distinct genus and species. In some respects they more nearly resemble the vertebræ on which Leidy based his description of *Ischyrotherium antiquum*.[b]

[a] Cont. Can. Pal., vol. 3, pt. 2, 1902, p. 32. [b] Proc. Acad. Nat. Sci. Philadelphia, 1856, p. 89.

URONAITES CETIFORMIS Cope.

Uronaites cetiformis Cope, 1876, Proc. Acad. Nat. Sci. Philadelphia, 1876, p. 346.

Founded on "cervical, dorsal, and caudal vertebræ, portions of limb, and rib bones" found near the top of the Claggett or base of the Judith River beds near Armell's (Amell's) Creek, a small tributary of Missouri River in northern Montana, at about the eastern limits of the Judith River basin as defined by Hayden.

ISCHYROTHERIUM cf. ANTIQUUM Leidy.

Ischyrotherium cf. *antiquum* Leidy, 1857, Proc. Acad. Nat. Sci. Philadelphia, 1856, p. 89.

We collected a number of vertebral centra from the marine horizon mentioned on page 42 as occurring within the usually recognized limits of the Judith River beds, which closely resemble those described and figured by Leidy[a] as the type of the present genus and species and which were obtained between Moreau and Grand rivers in South Dakota. Although Leidy states in his description that they were obtained "from an outlyer of the Great Lignite Tertiary formation" of that region, it is more than likely that the exact horizon was more nearly that of the Fox Hills or Pierre. However this may be, the vertebræ collected by us doubtless are from beds older than those which yielded the type of the genus and species. Whether the vertebræ in question pertain to *Ischyrotherium*, to one of the two previously mentioned genera of plesiosaurs, or to a distinct genus can be determined only by careful comparisons with the types, and the material is so incomplete that even then a fairly conservative paleontologist could not feel sure of his determination.

The plesiosaurs, like the fishes and the batrachians in the Judith River beds, afford very scanty and unsatisfactory evidence as to the age and proper correlation of the deposits.

CHELONIA.

Remains of chelonians are common in the Judith River beds. Altogether eight genera and fourteen species have been described from these deposits; most of these, unfortunately, are known from very fragmentary material, consisting for the most part of fragments of the carapace or plastron. In only a few instances is anything known of either the skull or the endo-skeleton.

TRIONYX FOVEATUS Leidy.

Trionyx foveatus Leidy, 1857, Proc. Acad. Nat. Sci. Philadelphia, 1856, p. 73.

The type of this species was collected by Doctor Hayden in the Judith River beds. The nature of the material upon which Leidy's

[a] Trans. Am. Philos. Soc., vol. 11, p. 150.

description of the species was based can be best appreciated by quoting his original description, which is as follows:

The species is founded on fragments of several costal and sternal plates. The exterior surface of the costal plates is covered with pits, excepting close to the margins; and the pits are small and round at the vertebral extremity, and gradually increase in size outwardly and become antero-posteriorly oblong, oval, and reniform. A vertebral fragment of a third or fourth costal plate, a little over an inch in length, is 11 lines wide and 2 lines thick. Small fragments of the sternal plates present an exterior surface covered with broken vermicular ridges and tubercles separated by wide intervals. Fragments of a hyposternal plate are 3 lines in thickness.

In a later paper[a] Doctor Leidy figures the type material and associates with it remains of another specimen collected by Hayden in the "Great Lignite Tertiary [probably Laramie] basin, near Long Lake, below Fort Clark," on Missouri River. He says of these remains that they are "not distinguishable from *Trionyx foveatus*," but adds that "the specimens are too imperfect positively to determine whether they actually belong to the same species." Considering the difference in the age of the deposits, it is quite probable that had better material been at the disposal of Doctor Leidy he would have found them to be at least specifically distinct.

Lambe[b] has described and figured much better material which he refers to this genus and species. His material was secured from the Judith River beds on the Red Deer River in Canada.

TRIONYX VAGANS Cope.

Trionyx vagans Cope, 1874, Ann. Rept. U. S. Geol. and Geog. Surv. Terr. for 1873, p. 453.

The original description of this species was as follows:

Represented by a number of costal bones and perhaps of sternals also. The former are rather light or thin for their width, and are marked with a honeycomb pattern of sculpture, in which the ridges are thin and much narrower than the intervening pits. They incline to longitudinal confluence at and near the lateral sutures. Several areæ are not infrequently confluent in a transverse direction near the middle of the bone.

Measurements.

	M.
Width of costal bone	0.0370
Thickness of costal bone	.0045

Four and five areæ in 0.010 m.

This species differs from the *T. foveatus* Leidy in the much narrower interareolar ridges and larger areæ, and in their longitudinal confluence at the margins, characters exhibited by numerous specimens.

Lignite Cretaceous of Colorado; near the mouth of the Bighorn River, Montana; Long Lake, Nebraska; found at the last two localities by Doctor Hayden.

[a] Trans. Am. Philos. Soc., vol. 11, 1860, p. 148, Pl. XI.
[b] Cont. Canadian Palæont., vol. 3, pt. 2, 1902, p. 33, Pl. I.

Lambe[a] has described and figured from the Judith River beds of the Red Deer River in Canada remains of a turtle which he refers to this species. By reference to his figures, however, it will be apparent to all that the specimen described by Lambe pertains to a species distinct from *T. vagans*. According to Lambe's figures the ridges on the surface sculpturing, instead of being "thin and much narrower than the intervening pits," as described by Cope, are heavy and broader than the intervening pits. There are other differences also of no less importance. It seems clear, therefore, that so far as our present knowledge goes the distribution of this species is limited to the Laramie, and that it should not be considered as a Judith River form.

PLASTOMENUS COALESCENS Cope.

Plastomenus coalescens Cope, 1875, Rept. U. S. Geol. Surv. Terr., vol. 2, p. 93, Pl. VIII.

This species is founded on fragments of plastron and carapace collected by George M. Dawson near Milk River, in Canada, from beds referred by Cope to the "Transition series, probably the Fort Union or Lignite epoch," but now known to belong to the Judith River series. The type material is extremely fragmentary and it would be difficult to identify other material by a comparison with Cope's description, his figures, or the type.

PLASTOMENUS COSTATUS Cope.

Plastomenus costatus Cope, 1875, Rept. U. S. Geol. Surv. Terr., vol. 2, p. 94, Pl. VIII.

Founded on fragments of carapace and plastron collected by Doctor Dawson in the same region and from the horizon from which he secured the type of the preceding species. The observations made concerning the preceding species apply also to this. While we do not doubt that the remains upon which these two species have been founded are specifically distinct, yet from their exceedingly fragmentary nature they are of little value in determining other material. It would scarcely be possible to definitely refer any material with certainty to either species, so imperfect are the types.

PLASTOMENUS PUNCTULATUS Cope.

Plastomenus punctulatus Cope, 1874, Ann. Rept. U. S. Geol. and Geog. Surv. Terr. for 1873, p. 453; 1875, Rept. U. S. Geol. Surv. Terr., vol. 2, p. 94, Pl. VI.

This species was "established on a costal bone found in association with the preceding species and referred to the genus *Plastomenus* provisionally, and with a possibility that it will be found not to pertain to it when fully known." Cope reports it also from the Lignite Cretaceous of Colorado and from Long Lake, Nebraska. The type of the present species is even more fragmentary than the types of the last two species.

[a] Cont. Canadian Palæont., vol. 3, pt. 2, 1902, p. 36, Pl. I.

PLASTOMENUS INSIGNIS Cope.

Plastomenus insignis Cope, 1874, Ann. Rept. U. S. Geol. and Geog. Surv. Terr. for 1873, p. 454; 1875, Rept. U. S. Geol. Surv. Terr., vol. 2, p. 95, Pl. VI.

This species is founded on "a portion of the right hyposternal bone of a tortoise about the size of the last species and from the same locality." A reference to the figure of the type published by Cope will serve to further emphasize the extremely fragmentary nature of the material upon which he based his description and the absolute hopelessness of referring with any degree of certainty other and better preserved material to this species.

Cope is not at all clear as to the locality or horizon from which the types of the last two species were derived. In describing *P. punctulatus* he says the type was found in association with the preceding species (*P. costatus*). The only locality given by him for the latter species is south of Woody Mount, near latitude 49°, British America. Then, in describing *P. insignis*, he says that the type was found in the same locality as the last species (*P. punctulatus*), the inference being, therefore, that it also was found near Woody Mount. At the close of his description of *P. punctulatus* he adds "Lignite Cretaceous of Colorado; also several fragments from Long Lake, Nebraska, from Doctor Hayden," while after the description of *P. insignis* he says, "Lignite Cretaceous of Colorado"—in neither instance making any reference to the Canadian locality. Now the localities given in the body of his descriptions of both these two species and those appended at the close are not only widely separated geographically, but the beds referred to are now known also to occupy very different stratigraphic positions. It would seem best to relegate both these species to the paleontologic scrap basket, since they are valueless from both a biologic and a stratigraphic standpoint.

ADOCUS LINEOLATUS Cope.

Adocus lineolatus Cope, 1874, Bull. U. S. Geol. and Geog. Surv. Terr., vol. 1, No. 2, p. 30; 1875, Rept. U. S. Geol. Surv. Terr., vol. 2, p. 92, Pl. VI.

According to Cope, this species was "established on a number of fragments from different exposures of the lignite beds primarily on a vertebral and sternal bone." The locality is given as "from lignite of Colorado, and mouth of Bighorn River, Montana," at neither of which localities are there any known exposures of the Judith River beds. The types were almost surely secured from the Laramie.

Lambe[a] has reported this species from the Judith River beds of Canada, and Cope[b] has included it in a list of vertebrates from the Judith River beds of Montana. Since in his several descriptions of material referred to this species Cope has nowhere mentioned any of

[a] Cont. Canadian Palæont., vol. 3, pt. 2, 1902, p. 38.
[b] Bull. U. S. Geol. and Geog. Surv. Terr., vol. 3, 1877, p. 573.

it as having been derived from the Judith River beds, it is more than probable that its appearance in Cope's list of Judith River vertebrates is due to an oversight. Considering the difference in age between the Judith River beds and the deposits which yielded the types of the species, together with the extremely fragmentary nature of the latter, as will readily appear from an examination of Cope's figures, it would seem quite probable that Lambe's identification of the "two well preserved fragments" from the Judith River beds of Canada, as pertaining to this species, may be incorrect, notwithstanding his remark that "this species is readily recognized by its neat and characteristic sculpture."

BASILEMYS OGMIUS (Cope).

Compsemys ogmius Cope, 1875, Rept. U. S. Geol. Surv. Terr., vol.2, p. 91.
Compsemys variolosus Cope, 1876, Proc. Acad. Nat. Sci. Philadelphia, 1876, p. 257.

This genus and species is based on fairly good material discovered by the Canadian Boundary Survey near Milk River, Canada, and supplemented by other material discovered by Mr. Charles H. Sternberg in the Judith River beds of Montana. Cope's original description was as follows:

Compsemys ogmius Cope. Represented in the collections of the British-American Boundary Commission by portions of the carapace and plastron. These are massive, and indicate a species of large size. As in other species of the genus, the external surface is a dense layer of cement or allied substance, which is sculptured with shallow pits.

A portion of the costal bone is concave and increases rapidly in thickness in one direction. The suture is coarse, but neither gomphosial nor squamosal. A portion of the plastron is thinner, not curved, and displays a very coarse median suture, in part squamosal in character. The sculpture consists of shallow pits not wider than the low, smooth ridges which separate them. There are deep superficial grooves marking the boundaries of dermal areas, a feature in which this tortoise differs much from the *P. coalescens* and resembles the species of *Compsemys*. Should marginal bones be found to exist in the *P. ogmius*, its reference to that genus will be further established.

From 6 miles west of first branch of Milk River, near latitude 49°.

The material discovered in Montana was referred to a distinct species, *Compsemys variolosus*, and described as follows:[a]

One of the most abundant and the largest species of the Fort Union beds. The carapace is convex and the plastron flat; the marginal bones are heavy and strongly convex on the inferior side. The margin of the plastron is thickened and heavy—characters which also belong to all parts of the carapace. The sutures of the dermal scuta are deeply impressed, and the surface of the bone is strongly sculptured above and below and even on the superior face of the thickened margins of the free lobes of the plastron. The sculpture consists of round fossæ, which are deeply impressed and are arranged quincuncially, so that their borders never form straight lines. The latter are also more or less angulate on the edge, so that the surface has a more than usually rugose character.

The typical specimen equals those of the large land tortoises of the Eocene in dimensions.

[a] Proc. Acad. Nat. Sci. Philadelphia, 1876, p. 257.

Lambe[a] has described and figured material pertaining to this species from the Judith River beds of Canada. He has also reported it from the Willow Creek division of the Canadian Laramie. It is not improbable that the latter reference is incorrect. Lambe has placed this species in the genus *Adocus*, but Hay[b] has made it the type of a new genus, *Basilemys*. Both these authors have accepted the specific name *variolosus* Cope, making *ogmius* Cope a synonym of *variolosus*, although *ogmius* was described a year before *variolosus*. We collected remains of this species at several localities.

BASILEMYS IMBRICARIUS (Cope).

Compsemys imbricarius Cope, 1876, Proc. Acad. Nat. Sci. Philadelphia, 1876, p. 257.

This species is based on material from the Judith River beds of Montana. The original description was as follows:

This species like the others of the genus, has the scutal sutures well defined, and the superficial surface of the carapace sculptured. The character of this sculpture distinguishes the species, and in the present instance in a special manner. It consists in the *C. imbricarius*, of excavations bounded on the sides by a short ridge each, which alternate with each other. Thus each bounding ridge terminates abruptly at the fundus of one of the fossæ, while the other end of the fossa rises and contracts to another ridge. The result is precisely that seen in the interior sculpture of Saracenic domes or niches, and is one which is quite unique among tortoises. The direction of the ridges is at right angles to the costal dermal sutures. This species was about as large as the snapping tortoise (*Chelydra serpentina*).

Measurements.

		M.
Thickness of a costal bone		0.0050
Three fossæ measure	lengthwise	.0065
	crosswise	.0050

POLYTHORAX MISSURIENSIS Cope.

Polythorax missuriensis Cope, 1876, Proc. Acad. Nat. Sci. Philadelphia, 1876, p. 258.

This genus and species was described by Cope from the Judith River beds of Montana. From his description, which is quoted below, it would appear to have been founded on ample material.

Char. Gen.—Plastron with contracted fixed lobes and wide bridge; carapace with well-developed marginal bones; mandibular ramus narrow; alveolar face with acute external margin; the symphysis neither produced nor recurved. Dermal scuta everywhere distinct, those of the plastron the usual ones, with the addition of the two marginal intergulars, and two large interhumerals. The latter scuta are separated from the humerals by sutures running parallel with the humeral margin of the anterior lobe between the gular and pectoral scuta.

In the possession of interhumeral scuta, *Polythorax* differs from any known genus of *Testudinata*. The general structure is much like that of *Adocus* and *Baëna*, with nearer resemblance to the latter in its double intergular scuta. It is impossible to ascertain whether there are intersternal bones, as the plastron is ossified throughout.

[a] Ottawa Naturalist, vol. 15, p. 63, Pls. III–VI, and Cont. Canadian Palæont., vol. 3, pt. 2, 1902, p. 39, Pl. II.

[b] Bull. U. S. Geol. Survey No. 179, 1902, p. 445.

The presence or absence of intermarginal scuta can not yet be determined, although it is clear, that if existing, their position is quite external.

This genus is interesting as connecting in its stratigraphical position allied types of Cretaceous No. 5 (*Adocus*), with those of the Wahsatch and Bridger Eocenes (*Baëna*).

Char. Specif.—Carapace with openly dentate posterior border. The surface is irregularly swollen, especially on the median line near the margins of the vertebral scuta. The vertebral scuta are wide, the costals short, and the marginals narrow. The anterior lobe of the plastron is a little shorter and more contracted than the posterior; its base is narrower than the antero-posterior extent of the bridge. Its extremity is rounded, while that of the posterior lobe is truncate with rounded angles. The gular and intergular scuta are each wider than long, while the interhumerals are much longer than wide. The humerals are narrow, while the pectorals are wide from the anterior position of the pectero-humeral suture. Each anal scutum is longer than wide.

The surface of the plastron is obsoletely but coarsely rugose; the roughness greatest anteriorly, where it consists of short raised lines irregularly disposed.

Measurements.

	M.
Length of plastron	0.183
Length of anterior lobe	.049
Length of bridge	.076
Width of bridge	.076
Width of extremity of posterior lobe	.035
Thickness of inguinal region	.010

From our present knowledge concerning the stratigraphic position of the Judith River beds it is evident that Cope was in error in supposing that this genus was intermediate between certain forms (*Adocus*) from the Fox Hills (Cretaceous, No. 5) and others pertaining to the genus *Baëna*, from the Wasatch and Bridger Eocenes.

BAËNA ANTIQUA Lambe.

Baëna antiqua Lambe, Cont. Canadian Palæont., vol. 3, pt. 2, 1902, p. 44.

This species is founded on portions of carapace and plastron, probably pertaining to a single individual, from the Judith River beds of the Red Deer River, Canada. Lambe's description of the species is as follows:

What is preserved of the carapace is in an excellent state of preservation. Five neurals in all are represented, with five pairs of costals. The sutures are sinuous and fine, but can be traced with ease. The sulci are very distinct.

The neurals are rather irregular in shape and of nearly equal size. The costals partake of the same irregularity of outline. The outer surface is almost smooth, the only unevenness being due to a few striations and depressed, roughened markings erratically disposed. Striations also occur at right angles to the sutures, forming an obscure border sculpture. The vertebral shields are broader than long, more especially the first one. The rib heads are well developed. There is a strong and abrupt thickening in the axillary region, but elsewhere the shell is thin. The anterior border is evenly rounded.

The front end of the plastron is rather broad in proportion to the length of its component parts, of which the epiplastrals, the entoplastral, and small portions of the hypoplastrals are preserved. The entoplastral, seen from below, is diamond shaped, a little broader than long, and placed far forward on account of the shortness of the

suture between the epiplastrals in front. Seen from above, or within, the entoplastral is much longer than broad, its breadth being reduced and its posterior half being prolonged backward. Similar extensions of the posterior border also occur in the upper surface of the epiplastrals. Sulci, as indicated in the figure, define the boundaries of the gular and intergular shields.

BAËNA HATCHERI Hay.

Baëna hatcheri Hay, Annals Carnegie Museum, vol. 1, p. 325.

The type of the present species was described by Hay from the Laramie deposits of Converse County, Wyo. It has been reported by Lambe[a] from the Judith River beds of Canada. Considering the difference in size, the variation shown in the different elements of the plastron as figured and described by Lambe, and the difference in stratigraphic position, there can be little doubt that Lambe was in error in referring his material to the present species, which may therefore be very properly excluded from the known species of the Judith River fauna. The material referred by Lambe to *B. hatcheri* should either be included in *B. antiqua* or made the type of a new species.

NEURANKYLUS EXIMIUS Lambe.

Neurankylus eximius Lambe, Cont. Canadian Palæont., vol. 3, pt. 2, 1902, p. 42.

This genus and species is based on portions of the posterior half of a carapace from the Judith River beds of Montana. According to Lambe, "the great development of the last neural by apparent coalescence with a suprapygal, the resulting compression of the pygal region, and the addition of a ninth pair of bones to the series of costals form a combination of characters that is both interesting and unique." The genus is considered by its author to show "greater affinity to the Chelydridæ than to any other group."

In addition to the forms mentioned above, Osborn[b] has mentioned *Compsemys victus* Leidy and *C. obscurus* Leidy as occurring in the Cretaceous of Montana, which might be taken as evidence that they also are Judith River forms. In no descriptions of either of these species can I find any suggestion that remains of either have been described from Montana. The types of both were from the Cretaceous near Long Lake, on Missouri River below Fort Clarke.

From the above remarks concerning the turtles of the Judith River beds it will be seen that while several of the included species have been founded on very fragmentary material, a few of them have been based on fairly complete specimens of either the carapace or plastron, or both. While some of the genera mentioned, like *Baëna* and *Adocus*, are of such persistent types that they may be considered, at present at least, as of comparatively little value for purposes of correlation, nevertheless when the chelonian fauna of these beds is known from more

[a] Cont. Canadian Palæont., vol. 3, pt. 2, 1902, p. 43.
[b] Ibid., p. 12.

complete material and is thoroughly studied it will doubtless prove to be quite different from that of the Laramie.

RHYNCOCEPHALIA.

CHAMPSOSAURUS Cope.

Champsosaurus Cope, Proc. Acad. Nat. Sci. Philadelphia, 1876, p. 348.

This genus was described by Cope from material consisting for the most part of detached and scattered vertebræ from the Judith River and Claggett beds of Montana. Vertebræ pertaining to representatives of the genus are common almost everywhere in the Judith River beds. They are perhaps the most abundant of the vertebrates of these beds. The vertebræ are easily recognized, though, as a rule, only the centra are preserved. These are biconcave or amphiplatyan, slightly keeled below and flat above, with a broad rib facet situated on the upper border and at about the middle of the centrum. Cope has distinguished four species of *Champsosaurus* from remains found in these beds.

CHAMPSOSAURUS PROFUNDUS Cope.

Champsosaurus profundus Cope, Proc. Acad. Nat. Sci. Philadelphia, 1876, p. 350.

This, the type species of the genus, was founded on a cervical, three dorsals, and a sacral, presumably from the same individual, from the Judith River beds. Distinguished chiefly by the great development of the inferior keel.

CHAMPSOSAURUS ANNECTENS Cope.

Champsosaurus annectens Cope, Proc. Acad. Nat. Sci. Philadelphia, 1876, p. 351.

In describing this species Cope remarks that "the greater number of vertebræ obtained belong to this saurian, which may therefore be looked upon as the type of the genus." Since, however, the preceding species was described first, it would perhaps be better to follow the regular rule in such cases and regard it as the type of the genus, as was done by Hay in his Catalogue of American Fossil Vertebrates. The species is founded on several vertebræ, of which Cope remarks: "I can not certainly connect the vertebræ of a series as those of a single individual."

This species has been reported by Lambe[a] from the Judith River beds of Canada.

CHAMPSOSAURUS BREVICOLLIS Cope.

Champsosaurus brevicollis Cope, 1876, Proc. Acad. Nat. Sci. Philadelphia, 1876, p. 352.

This species is founded on a single cervical vertebra, of which Cope remarks as follows:

The evidence for the existence of this species must be allowed to rest at present on a cervical vertebra, with free hypapophysis. This body differs from the corresponding

[a] Cont. Canadian Palæont., vol. 3, pt. 2, 1902, p. 45.

one in the *C. annectens* in its greater brevity as compared with its length. The vertical and transverse diameters exceed the longitudinal in the *C. brevicollis*, while in the *C. annectens* the length exceeds both. The inferior aspect of this centrum is broadly rounded, not carinate as in *C. annectens*. The value of this character is uncertain, but a centrum similarly rounded below (above alluded to) has the more elongate form of the *C. annectens*.

CHAMPSOSAURUS VACCINSULENSIS Cope.

Champsosaurus vaccinsulensis Cope, 1876, Proc. Acad. Nat. Sci. Philadelphia, 1876, p. 353.

This species is founded on a single vertebra. It is defined by Cope as follows:

This reptile is indicated by a posterior dorsal vertebra in which the common base of the neural arch and diapophysis is decurved to below the middle of the side of the centrum. This surface has somewhat the outline of the section of a T-rail, the inner portion being on the superior face of the centrum. The centrum is shorter than the corresponding ones of the *C. annectens* and *C. profundus*, so that the basis of the neural arch approaches near the borders of the articular faces above. The centrum is perforated by two vertical foramina as in most *Sauropterygia*. The osseous tissue of the bone is quite dense and the surface is smooth.

Measurements.

		M.
Diameter of centrum.	antero-posterior	0.026
	vertical	.029
	transverse	.045

Besides the much larger size, this species differs from those previously referred to this genus in almost all details of proportion, etc.

From Cope's description of the vertebra which constitutes the type of this species it would appear not unlikely that it pertains to a genus distinct from *Champsosaurus*, though from the nature of the type it must be evident to all that it is impossible to properly define either the genus or the species to which it pertains.

Of the three preceding species of *Champsosaurus* it may be remarked that, while it is more than probable that several species pertaining to this genus are represented in the Judith River beds, yet, owing to the fragmentary and disarticulated nature of the remains upon which Cope based his descriptions, he was unable to properly define any of the species, and it would be quite impossible to refer any material with certainty to any of the species described by him. It has yet to be shown that most of the characters mentioned by Cope as distinguishing his species are not present in vertebræ from different regions of the vertebral column in the same individual. Mr. Barnum Brown has been recently engaged in making a study of some most excellent skeletons of *Champsosaurus* collected by himself in the Laramie. When the results of his studies are published we shall doubtless know more of the structure of the Cretaceous rhyncocephalians and be able to arrive at a more definite conclusion concerning the nature and validity

of the various species named by Cope. Owing to the fact that these Judith River forms are known almost exclusively from disarticulated vertebral centra, and considering the usually very simple structure of these throughout the entire vertebral column in this group, it may at present be considered difficult, if not impossible, to distinguish the Judith River forms from one another or from the later Laramie forms. Vertebræ of the character now known to pertain to *Champsosaurus* were first described and figured by Leidy[a] as belonging to *Palæoscincus costatus*. They are now, however, known to have been associated with teeth entirely different from those described and figured as the type of that genus and species.

CROCODILIA.

CROCODILUS HUMILIS Leidy.

Crocodilus humilis Leidy, 1857, Proc. Acad. Nat. Sci. Philadelphia, 1856, p. 73.

This species was founded on a number of teeth from the Judith River beds of Montana. Leidy's original description was as follows:

> The species is founded on ten specimens of shed crowns of teeth, apparently of a small species of crocodile. The largest specimen is 7½ lines long and 3½ lines in diameter at base, which is nearly circular. Another specimen is 7 lines long and 2½ lines in diameter at base, and a third specimen is 6 lines long and 3½ lines in diameter at base. These are all moderately curved conical, nearly circular in transverse section, with the two usual internal acute ridges, and with the intervening surfaces slightly striate or nearly smooth. The crown of a posterior tooth is compressed, mammillary in form, 2½ lines long and 2½ wide at base, with the summit obtuse, and the sides finely and longitudinally rugose.

From the above description it will readily appear that the simple conical teeth upon which the species was based furnish no characters for the positive identification of other material.

BOTTOSAURUS PERRUGOSUS Cope.

Bottosaurus perrugosus Cope, 1874, Bull. U. S. Geol. and Geog. Surv. Terr., vol. 1, No. 2, p. 26.

This species is founded on "numerous fragments with vertebræ and portions of skull" from Laramie deposits of eastern Colorado.

Lambe[b] has reported this species from the Judith River beds of the Red Deer River in Canada. Considering the fragmentary nature of the type material and the difference in the age of the deposits, Lambe's identification may be incorrect. It would seem better to accept it as only provisional until such time as the Crocodilia of the Judith River beds and the Laramie have been studied from more perfect material.

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[a] Trans. Am. Philos. Soc., vol. 2, p. 146, Pl. IX.

[b] Cont. Canadian Paleont., vol. 3, pt. 2, 1902, p. 48.

DINOSAURIA.

A number of genera and species of dinosaurs have been proposed by Leidy, Cope, and Marsh, based upon detached teeth from the Judith River beds, although nothing definite is known concerning the nature of the animals to which they pertained. Some of these have been considered as pertaining to the Lacertilia, others to the Dinosauria, and still others to the Mammalia. I shall consider them collectively, however, as doubtfully pertaining to the Dinosauria. They are all founded on such fragmentary material as to be of little value except as bearing evidence of the diversity of the fauna.

TROÖDON FORMOSUS Leidy.

Troödon formosus Leidy, 1857, Proc. Acad. Nat. Sci. Philadelphia, 1856, p. 72; 1860, Trans. Am. Philos. Soc., vol. 11, p. 147, Pl. IX.

This genus and species was founded on the crown of a single tooth from the Judith River beds of Montana. Teeth of very similar size and pattern are not uncommon in the Laramie of Converse County, Wyo. Lambe[a] has reported the genus and species from the Judith River beds of Canada.

DEINODON HORRIDUS Leidy.

Deinodon horridus Leidy, 1857, Proc. Acad. Nat. Sci. Philadelphia, 1856, p. 72; 1860, Trans. Am. Philos. Soc., vol. 11, p. 143.

This species was originally founded on a number of detached teeth from the Judith River beds, evidently pertaining to more than one genus and species, as was subsequently recognized by Leidy[b] when he made the more problematical of the teeth at first referred to this genus and species the type of a new genus and species, *Aublysodon mirandus*. The remaining teeth referred by Leidy to the present genus clearly pertain to members of the carnivorous Dinosauria.

AUBLYSODON MIRANDUS Leidy.

Aublysodon mirandus Leidy, 1868, Proc. Acad. Nat. Sci. Philadelphia, 1868, p. 198.

This species was founded on detached teeth from the Judith River beds of Montana. These teeth are variable in size and character. Their nature is problematical. Marsh has suggested that some of the smaller forms might possibly be mammalian. It seems more probable, however, that they are all reptilian and that they pertain to some form of carnivorous dinosaur. In general form the teeth are subconical, flattened on one side and convex on the other, with a rather blunt apex. Teeth of this character are fairly common both in the Judith River beds and the Laramie. Marsh[c] has named without

[a] Cont. Canadian Palæont., vol. 3, pt. 2, 1902, p. 47.
[b] Proc. Acad. Nat. Sci. Philadelphia, 1868, p. 198.
[c] Am. Jour. Sci., 3d ser., vol. 44, 1892, pp. 174 and 175, Pl. III.

describing two species of the present genus, *A. amplus* and *A. cristatus*, from material found "in the Ceratops beds of Montana and Wyoming." Since neither of these species was properly described by Marsh, they may as well be abandoned. While, as remarked above, teeth of the same pattern as those described and figured by Leidy are common in both the Laramie and the Judith River beds, they do not of themselves afford characters of sufficient importance to distinguish either genera or species.

PARONYCHODON LACUSTRIS Cope.

Paronychodon lacustris Cope, 1876, Proc. Acad. Nat. Sci. Philadelphia, 1876, p. 256.

This species was founded on detached teeth with subconic crowns, "one side of which is convex and the other side plane." After a comparison of Cope's description of the present genus and species with Leidy's description and figures of the preceding, it is evident that the teeth described by Cope are of the same form as those described by Leidy. Since Cope's material was derived from the same general locality in the Judith River beds as Leidy's, the last-named genus and species may well be considered a synonym of the first.

ZAPHSALIS ABRADUS Cope.

Zaphsalis abradus Cope, 1876, Proc. Acad. Nat. Sci. Philadelphia, 1876, p. 344.

This species was founded on detached teeth from the Judith River beds of Montana. The meager description given by Cope without figures renders it impossible to certainly identify any of the forms of teeth known from these deposits with those referred to by Cope in his description. It seems probable, however, that his description was based on certain small teeth found not very abundantly in both the Laramie and the Judith River beds and characterized by sharp, compressed crowns, broad at base and pointed above, flat on one side and gently convex on the other, with denticulate posterior and smooth anterior border. The flat surfaces of these teeth are distinctly striated and have the appearance of having been applied to one another in a manner like that of the inner surfaces of the anterior pair of incisors in some rodents. They evidently pertain to the Reptilia, and may represent anterior teeth which occupied a position in the jaw similar to that of the incisors in certain Mammalia. Their exact nature must, however, for the present at least, remain uncertain.

THEROPODA.

DEINODON Leidy.

Deinodon Leidy, 1857, Proc. Acad. Nat. Sci. Philadelphia, 1856, p. 72.

Cope[a] has pointed out that *Deinodon* Leidy was essentially preoccupied by *Dinodon*, applied by Dumferil in 1853 to a genus of reptiles. Cope by reason of this substituted the genus *Lælaps*,[b] founded in 1866 on material from the Greensands of New Jersey, overlooking the fact, later pointed out by Marsh[c], that *Lælaps* was also preoccupied, having been applied by Koch in 1835 to a genus of Arachnida. At the same time Marsh proposed the generic name *Dryptosaurus* to replace *Lælaps*. Considering that Leidy's spelling of the name *Deinodon* differed from that of Dumferil, not a few naturalists would be in favor of retaining the former as a good generic name. It is retained here for those carnivorous dinosaurs with teeth after the pattern of those to which it was restricted by Leidy in 1859. Should this name be abandoned as preoccupied it would perhaps be best to give to these Judith River carnivorous dinosaurs a new generic name rather than to refer them to *Dryptosaurus*, founded, as we have seen, on material from the New Jersey Greensands.

Besides the type species, *D. horridus*, already mentioned as having been described by Leidy from detached teeth from the Judith River beds of Montana, a number of other specific names have been proposed, more especially by Cope, for fragmentary remains from these deposits. These so-called species have been referred sometimes to the present genus, sometimes to *Lælaps*, *Aublysodon*, *Dryptosaurus*, etc. I shall refer to them all under the present genus.

DEINODON LATERALIS (Cope).

Aublysodon lateralis Cope, 1876, Proc. Acad. Nat. Sci. Philadelphia, 1876, p. 248.

This species is founded on detached teeth from the Judith River beds of Montana. From Cope's description of this species it is evident that the teeth upon which it is based belonged to the genus *Deinodon* rather than *Aublysodon*, as those genera were restricted by Leidy. Considering the heterodont nature of the teeth in those carnivorous dinosaurs, it is doubtful if the present species is distinct from the type of the genus.

DEINODON INCRASSATUS (Cope).

Lælaps incrassatus Cope, 1876, Proc. Acad. Nat. Sci. Philadelpia, 1876, p. 248.

This species was founded on "two teeth, a larger and a smaller, which were found near each other, but not sufficiently so as to war-

[a] Trans. Am. Philos. Soc., vol. 14, 1870, p. 117.
[b] Proc. Acad. Nat. Sci. Philadelphia, 1866, p. 276.
[c] Am. Jour. Sci., 2d ser., vol. 14, 1877, p. 88.

rant the belief that they pertain to the same individual." These teeth are probably from near the anterior and posterior extremities of the series in some representative of *D. horridus* Leidy.

DEINODON EXPLANATUS (Cope).

Lælaps explanatus Cope, 1876, Proc. Acad. Nat. Sci. Philadelphia, 1876, p. 249.

This species was founded on numerous teeth of an apparently small carnivorous dinosaur from the Judith River beds of Montana. So far as it is possible to determine its characters from the teeth alone, it appears to be quite distinct from any of the others. Teeth similar in character to those described by Cope are common in both the Judith River beds and the Laramie. Cope has described the crowns of these teeth as "strongly compressed and curved; one side is flat, the other gently convex." It is probable that the teeth described by Cope occupied a median position in the jaw and that the flat surface was the inner.

DEINODON FALCULUS (Cope).

Lælaps falculus Cope, 1876, Proc. Acad. Nat. Sci. Philadelphia, 1876, p. 249.

This species is founded on several teeth from the Judith River beds of Montana. According to Cope, they are of about half the size of those of the last-mentioned species and are relatively shorter, stouter, and less sectorial in character. They may represent anterior teeth of that species.

DEINODON HAZENIANUS (Cope).

Lælaps hazenianus Cope, 1876, Proc. Acad. Nat. Sci. Philadelphia, 1876, p. 343.

This species is founded on seven detached teeth from different localities. Teeth of the character of those described by Cope are not uncommon in both the Laramie and the Judith River beds. They appear to pertain to the anterior dentition of some of these carnivorous dinosaurs, probably of *D. horridus*.

DEINODON LÆVIFRONS (Cope).

Lælaps lævifrons Cope, 1876, Proc. Acad. Nat. Sci. Philadelphia, 1876, p. 344.

This species is founded on a single tooth from the Judith River beds of Montana. It is distinguished by the absolutely smooth character of the anterior edge, a character of doubtful value.

DEINODON CRISTATUS (Cope).

Lælaps cristatus Cope, 1876, Proc. Acad. Nat. Sci. Philadelphia, 1876, p. 344.

This species is founded on detached teeth from the Judith River beds resembling those of *Troödon* in character and size, and possibly pertaining to that genus.

ORNITHOMIMUS Marsh.

Ornithomimus Marsh 1890, Am. Jour. Sci., 3d ser., vol. 34, p. 84.

The present genus was based upon material from the Laramie (Denver) beds of eastern Colorado. Other species referred to the same genus by Marsh were secured in Cretaceous deposits in the Judith River region of Montana.

ORNITHOMIMUS TENUIS Marsh.

Ornithomimus tenuis Marsh, 1890, Am. Jour. Sci., 3d ser., vol. 34, p. 85.

This species is founded on a portion of a third metatarsal from the Judith River beds of Montana.

ORNITHOMIMUS GRANDIS Marsh.

Ornithomimus grandis Marsh, 1890, Am. Jour. Sci., 3d ser., vol. 34, p. 85.

This species is founded on fragments representing a considerable portion of a skeleton from the Eagle sandstones near the mouth of Cow Creek, opposite Cow Island, on the north side of Missouri River, Montana. This species, which is much the largest of this genus, has been erroneously referred to the Judith River beds. Our researches in the season of 1903 demonstrated conclusively that the sandstones from which it was obtained belong to the Eagle formation and pertain to a horizon decidedly older than the Judith River beds. Hereafter it should be referred to the Eagle formation. It was a reptile of enormous proportions. The third metatarsal, according to Marsh, has a length of 600 mm., and was 90 mm. in transverse and 80 mm. in antero-posterior diameter at its distal extremity.

ORNITHOMIMUS ALTUS Lambe.

Ornithomimus altus Lambe, 1902, Cont. Canadian Palæont., vol. 3, pt. 2, p. 50.

This species is based on considerable portions of the skeleton from the Judith River beds of the Red Deer River region in Canada. According to Lambe's description of the species, the type may be considered as consisting of "a complete hind limb (including the foot), the phalanges of the left foot in place, a pubic bone, and an ischium, of one individual (No. 930 Can. Geol. Survey)." The present species appears, from Marsh's very meager description, to be very closely related to, if not identical with, that of *O. tenuis* Marsh, based upon material from the same beds in Montana.

Although the genus *Ornithomimus* represents the most highly specialized theropod dinosaurs found in these beds, they are at present represented in our various museums by such meager material that it is as yet quite impossible to determine many of the more important characters of the genus or to satisfactorily compare the various species with one another. Whenever by the discovery of more

perfect material it shall become possible to make comparative studies of the various species of Ornithomimidæ now reported from the Eagle formation, the Judith River beds, and the Laramie, they will doubtless prove to exhibit many anatomical differences, perhaps even of generic importance, and show various degrees of specialization which are at present not discernible.

PREDENTATA.

STEGOSAURIA.

PALÆOSCINCUS COSTATUS Leidy.

Palæoscincus costatus Leidy, 1857, Proc. Acad. Nat. Sci. Philadelphia, 1856, p. 72.

In proposing the genus and species Leidy remarks as follows:

The genus and species is founded on a single specimen of a tooth of a lacertian, discovered by Doctor Hayden.

The crown of the tooth is palmate, with eight radiating costæ terminating at the margin in more or less developed points. The fang is flattened, cylindrical, and is hollow; and it expands into a ridge surrounding the base of the crown. Breadth of the crown 4 lines, length 2½ lines; width of the fang 2 lines, thickness 1 line. Whole length of the specimen 4 lines.

This tooth was subsequently figured and described[a] in greater detail by Doctor Leidy. In this description it was provisionally associated with certain vertebræ now known to belong to the rhyncocephalian genus *Champsosaurus*.

Teeth of the same general form and pattern as that described and figured by Leidy are common in the Judith River beds and the Laramie. As yet they have only been found detached, so that nothing is positively known as to the nature of the animals to which they belonged. On account of their close resemblance to the teeth of stegosaurian reptiles from the Jurassic, they have been very generally considered as pertaining to representatives of the Stegosauridæ.

Lambe[b] has reported this species from the Judith River beds of the Red Deer River region in Canada. We found teeth not specifically distinguishable at various localities both in Canada and in Montana.

PALÆOSCINCUS ASPER Lambe.

Palæoscincus asper Lambe, 1902, Cont. Canadian Palæont., vol. 3, pt. 2, p. 54, Pl. XVII.

This species is founded on the crown of a single tooth from the Judith River beds of the Red Deer River region in Canada. According to Lambe, the present species is distinguished as follows: "The serrations are more numerous, the sides more conspicuously ridged, whilst the double row of denticles at one end of the cutting edge, besides being novel, is most interesting and instructive, in that it is

[a] Trans. Am. Philos. Soc., vol. 11, 1860, p. 146, Pl. IX.
[b] Cont. Canadian Palæont., vol. 3, pt. 2, 1902, p. 58.

suggestive of a progressive step toward the development of a double row of tubercles such as is found in the molars of the Multituberculates." I am of the opinion that the characters mentioned above may be due to age or the position occupied by the tooth in the jaw, rather than to any specific distinction.

STEREOCEPHALUS TUTUS Lambe.

Stereocephalus tutus Lambe, 1902, Cont. Canadian Palæont., vol. 3, pt. 2, p. 55, Pls. XI, XII, XXI.

The present genus and species has been described by Lambe from remains pertaining to several individuals, for the most part found dissociated in the Judith River beds of the Red Deer River region in Canada. Lambe's description was based on material believed by him to represent parts of the skull, the ribs, teeth, dermal scutes, and spines or plates. He refers the genus to the Stegosauridæ, and it appears more than probable that the tooth figured by him in the text may pertain to some member of that family, though it remains to be shown that it is distinct from the previously mentioned genus. This tooth certainly resembles very closely a large and worn tooth of *Palæoscincus*.

The fragment of skull, together with the five-keeled bony scutes found in connection with it, may or may not pertain to the same genus as the tooth and detached dermal plate. There is considerable evidence, however, for referring them to the Crocodilia rather than the Dinosauria. Scutes very similar to those figured and described by Lambe, though of much smaller size, are common in the living cayman and other members of the Crocodilia, while remains of crocodiles of gigantic size are known to occur in the Judith River beds. It seems not impossible, therefore, that remains of reptiles pertaining to two distinct orders have been associated in the description of this genus.

CERATOPSOIDEA.

CERATOPSIDÆ.

Marsh[a] proposed the family name Ceratopsidæ, from the genus *Ceratops*, to include a group of quadrupedal horned herbivorous dinosaurs from the Judith River beds and the Laramie. This family included, perhaps, the most highly specialized members of the predentate dinosaurs. It reached its culmination in the Laramie, where it was represented by numerous individuals pertaining to several genera and species. In Judith River times, however, the family had already acquired a marked degree of specialization, and was represented by at least two or three genera and several species pertaining to decidedly more primitive types than the later Laramie forms. At

[a] Am. Jour. Sci., 3d ser., vol. 36, 1888, p. 478.

present two genera are clearly recognizable among the remains of Judith River Ceratopsidæ. A number of other genera supposed to belong to this family have been referred to these beds. Some of these genera are based on such fragmentary material that it is quite impossible to identify them specifically or to determine their relations. Some genera are known to belong to other families of the Dinosauria, and one or two have been referred by some authors to these beds the types of which it seems more than probable were derived from the Laramie, although no definite statement was made by their author as to their geographic or stratigraphic position beyond the fact that they were from the Laramie. This assertion might now be taken as meaning anywhere from the base of the Judith River beds to the top of the Fort Union.

DYSGANUS Cope.

Dysganus Cope, 1876, Proc. Acad. Nat. Sci. Philadelphia, 1876, p. 250.

The present genus was the first to be proposed for these dinosaurs. Unfortunately it was based on such imperfect material that Cope was unable to describe it in such a manner that it can be identified with certainty. The genus was founded on a number of detached teeth pertaining both to members of the present family and to the Trachodontidæ, a family of bipedal dinosaurs common also in the Judith River beds. Cope proposed four species based upon the remains of teeth referred to *Dysganus*. Since all of these species are unidentifiable, it is only necessary to mention them in this connection. They are as follows: *Dysganus bicarinatus*, *D. encaustus*, *D. haydenianus*, *D. peiganus*.

MONOCLONIUS Cope.

Monoclonius Cope, 1876, Proc. Acad. Nat. Sci. Philadelphia, 1876, p. 255.

This is perhaps the best known dinosaurian genus from the Judith River beds. Although distinguished chiefly by its cranial characters, the remainder of the skeleton is also fairly well known. Altogether seven species have been referred to this genus—four by Cope and three by Lambe. After a careful study of the remains upon which these various species were based, it is evident that they pertain to more than one genus.

Considering *Monoclonius crassus* Cope, the first species described, as the type of the genus and basing our diagnosis of the genus upon the material used by Cope in defining this species, the present genus may be distinguished by the following characters: Parietals perforated by lateral fontanelles of moderate dimensions separated by a broad, thin, median parietal bar. Sutures for squamosals much abbreviated, indicative of short and proportionally broad squamosals. Supraorbital horn cores very short, straight, and triangular in cross section. Nasal horn long and curved backward.

MONOCLONIUS CRASSUS Cope.

Monoclonius crassus Cope, 1876, Proc. Acad. Nat. Sci. Philadelphia, 1876, p. 255.

This species is founded on a sacrum, several vertebræ, limb bones, portions of skull, teeth, etc., from the Judith River beds of Montana. Owing to the imperfect nature of the material, together with the unusual form of some of the elements, which are so strikingly different from those in all other known reptiles, Cope's description of this species was erroneous in many respects, as will appear from the following quotation:

> Sacrum with ten vertebræ, the last centrum much compressed, the dyapophyses extending horizontally from the neural arch above, and connected by a vertical lamina with the iliac supports; length, 27.33 inches. The bones of the limbs are robust, the hinder the longer, but not so much so as in some other genera. Length of femur, 22 inches; greatest diameter, proximally, 8 inches; distally, 7.25 inches. The three anterior dorsal vertebræ are coossified, and the first exhibits a deep cup for articulation with the preceding vertebra. The episternum is a T-shaped bone, thin and keeled on the median line below. Length of transverse portion, 21 inches.

The three coossified vertebræ are now known to be the anterior cervicles instead of the dorsals, while the "episternum" is in reality the parietal. Cope's description of the teeth and their method of replacement is likewise erroneous. The teeth in the present genus, instead of resembling those of *Hadrosaurus* and being replaced from in front as in that genus as stated by Cope, differ markedly from the teeth in any of the bipedal dinosaurs. The crowns of the teeth in *Monoclonius*, as in all the Ceratopsidæ, are compressed and acuminate, There is a strong median vertical keel on the external wall in the upper teeth and a similar one on the internal wall of the lower teeth. In the unworn teeth the opposite walls of both the inferior and the superior teeth present a broad keel. The teeth are replaced from beneath and not from the "front," as in *Hydrosaurus*. All the adult teeth, save, perhaps, those at either extremity of the dental series, are two rooted.

MONOCLONIUS DAWSONI Lambe.

Monoclonius dawsoni Lambe, 1902, Cont. Canadian Palæont., vol. 3, pt. 2, p. 57, Pl. XVI, XIX, XX.

This species is founded on a considerable portion of a skull from the Judith River beds of Canada. The type (No. 1173, Can. Geol. Survey) consists of a very fragmentary skull with large and somewhat compressed nasal horn core curved backward, ovate in cross section with the broad end of the oval directed anteriorly. The orbit is nearly circular, and there still remains in the type the base of a small rudimentary supraorbital horn core, notwithstanding Lambe's statement that it shows no trace of a horn core. This rudimentary horn core is flattened on its external surface as in the cotype of *Monoclonius crassus* Cope. The apex of this horn is wanting in the present specimen. A

fragment of the parietal is preserved, showing three or four of the marginal undulations. These resemble those seen in the type of *Monoclonius crassus* Cope, and I am inclined to regard the present species as closely allied to, if not identical with, the *M. crassus* of Cope. The nasal horn and orbit are very large when compared with the occipital condyle, the maxillaries, and the quadrate.

The peculiar parietal associated by Lambe with the type of *M. dawsoni* may be regarded as pertaining to a distinct species and perhaps also to a distinct genus. The median parietal bar is very heavy and deeply emarginate posteriorly, where on either side it gives off an elongated process which is pointed and curves inward and slightly downward. The bases of these processes are separated from one another by a distance of 300 mm. They are each 109 mm. in length, have a breadth of 112 mm. at the base, and a thickness of 30 mm. They are acutely pointed, have rugose surfaces with deep vascular grooves, and in life were evidently ensheathed in horn. The posterior border of the parietal between the bases of these processes is very thick and rounded. On the superior surface, in the middle just in front of the posterior border, there is a rather deep concavity. The median bar of the parietal is very thick throughout its entire length. Its superior surface is marked by a number of very gentle elevations; it is rugose and shows shallow vascular impressions. Besides the processes already mentioned as present on the posterior portion of the parietals, there is on either side a series of seven emarginations on the parietal borders, separated by as many prominences. The posterior of these prominences are the larger, and they each bear evidence of having supported a distinct epoccipital bone during the life of the animal, save perhaps the two anterior, which appear to have been overlapped by the squamosal, since the parietal in this region presents a rather distinct sutural surface for contact with the squamosal. The parietals on either side of the median bar present a large fontanelle, and the margin of bone inclosing this is very thin. These fontanelles have a length of 292 mm. and a breadth of 254 mm. The parietal bar is concave on its inferior surface, and more especially anteriorly. At its anterior extremity it presents a number of cavities and articulates with the postfrontals.

One-half of a horn core, split longitudinally and found with this peculiar parietal (No. 971, Can. Geol. Survey) referred by Lambe, though I think erroneously, to *M. dawsoni*, appears to represent one-half of a nasal horn of the type described by Cope as *M. sphenocerus*. Owing to the imperfect nature of this specimen it is not possible to determine positively whether it represents a nasal or a supraorbital horn core. It seems more than probable that this type of parietal was associated with a nasal horn similar to that of *M. sphenocerus*. If the horn core should prove to be a supraorbital the evidence would be equally in favor of excluding it and the associated parietals

from the present species, whose very rudimentary supraorbital horn core is widely different. It seems quite probable that this peculiar parietal may pertain to *M. sphenocerus*. From the nature of the associated horn core it can not pertain to *M. dawsoni*.

MONOCLONIUS SPHENOCERUS Cope.

Monoclonius sphenocerus Cope, 1889, Am. Naturalist, vol. 23, p. 716, Pl. XXXIII.

This species is founded on a premaxillary, a nasal, and a nasal horn core from the Judith River beds. The nasal horn core of the present species is the largest and most powerful observed in the Ceratopsidæ. It is perfectly straight and was directed upward and slightly backward. The anterior border is sharp throughout its entire length; the posterior is broadly rounded. No other portions of the skull are associated with the type, so that it is impossible to determine from it the character of the frill or parietal crest. As stated above, a portion of a horn core found associated with the peculiar parietal referred by Lambe to *M. dawsoni* resembles the nasal horn of the present species, and it is not improbable that the parietal figured and described by Lambe pertains to the present species rather than to *M. dawsoni*. If so, this would seem to emphasize the distinctive characters of the present species, which might then even be considered as generically distinct from the other known species.

MONOCLONIUS FISSUS Cope.

Monoclonius fissus Cope, 1889, Am. Naturalist, vol. 23, p. 717.

This species is founded on an imperfect pterygoid described as a squamosal. The type is not sufficient to afford an adequate description of the species, and the latter should be abandoned.

The three remaining species referred by their authors to this genus are here regarded as pertaining to the next genus.

CERATOPS Marsh.

Ceratops Marsh, 1888, Am. Jour. Sci., 3d ser., vol. 36, p. 477, Pl. II.

This genus was founded on an occipital condyle and a pair of supraorbital horn cores from near the summit of the Judith River beds in Montana. The horn cores toward the top are nearly circular in cross section instead of being flattened on the external side as in *Monoclonius* Cope. They are much longer than in the type of that genus and are somewhat curved, though not so much so in *C. montanus* Marsh, the type species, as in some of the other forms here referred to this genus. Combining the characters shown by the types of the several species referred to the present genus, it may be defined as follows: Parietals reduced to a narrow median bar and slender posterolateral processes, inclosing on either side large elongated parietal fontanelles. External branches of parietals overlapped by the elongated

and triangular squamosals. Supraorbital horn cores well developed, circular in cross section except near the base, and curving backward and outward. Nasal horn core strong and curved forward instead of backward as in *Monoclonius*.

CERATOPS MONTANUS Marsh.

Ceratops montanus Marsh, 1888, Am. Jour. Sci., 3d ser., vol. 36, p. 477, Pl. II.

This, the type species of the genus, was founded, as stated above, on an occipital condyle and a pair of supraorbital horn cores from the Judith River beds of Montana. The elongate supraorbital horn cores, circular in cross section, easily serve to distingush the present genus and species from *Monoclonius crassus*, and subsequent discoveries have shown that this type of horn core was associated with other distinctive cranial characters of still greater importance.

CERATOPS RECURVICORNIS (Cope).

Monoclonius recurvicornis Cope, 1889, Am. Naturalist, vol. 23, p. 716, Pl. XXXIV [XXIV].

The species is founded on nasal and supraorbital horn cores and other parts of the skull pertaining to the same individual from the Judith River beds of Montana. The forward curve of the nasal horn, the presence of a rudimentary horn on the surface of the frontals a little in advance of the orbit, and the well-developed supraorbital horn cores are characteristic of this species. Owing to the immature age of the individual to which the type pertained, the supraorbital horn cores have not assumed their adult form and appear somewhat intermediate between those forms which are characteristic of *Ceratops* and those found in *Monoclonius*, though they are decidedly nearer that of the former genus.

CERATOPS CANADENSIS (Lambe).

Monoclonius canadensis Lambe, 1902, Cont. Canadian Palæont., vol. 3, pt. 2, p. 63, Pls. XVII, XVIII.

This species is founded on a portion of a skull and a lower jaw. With the skull there is a nasal without the horn, erroneously considered by Lambe as a jugal part of the frontal region with the horn, a squamosal, and a portion of the slender external bar of the parietal. The supraorbital horn core in the present species is well developed, circular in cross section, and curves backward, all of which characters readily distinguish it from the short triangular horn cores of *Monoclonius*. The long triangular squamosal is quite different from that which the squamosal suture of the parietal would indicate as having been present in the latter genus. The fortunate discovery made by Mr. Lambe in the Judith River beds of Canada, in which he found the type of the present species, fixes with reasonable certainty the character of parietal and squamosal that were associated with the type of supraorbital horn seen in *Ceratops montanus*.

CERATOPS BELLI (Lambe).

Monoclonius belli Lambe, 1902, Cont. Canadian Palæont., vol. 3, pt. 2, p. 66, Pl. XX.

This species is founded on a portion of a parietal from the Judith River beds of Canada. The portion of parietal found in place with the squamosal in the type of the preceding species is of such a character as to render it more than probable that the present species is not specifically distinguishable from *C. canadensis*, as will appear from the following quotation taken from Lambe's description of the squamosal of *Ceratops canadensis*.

> The lower surface near and parallel to the inner posterior end is broadly and shallowly grooved for the reception of a long, slender bone, triangular in section, that projects backward and inward, its outer edge continuing the curve of the squamosal. Probably this slender bone represents the anterior end of a forwardly bent, side extension of the parietal, such as occurs in the species *Monoclonius belli*.

The type of the present species would seem, therefore, to be of more value as furnishing direct evidence as to the character of the parietals in the genus *Ceratops* than as representing a new species.

CERATOPS PAUCIDUS Marsh.

Ceratops paucidus Marsh, 1889, Am. Jour. Sci., 3d ser., vol. 37, p. 336; 1890, Am. Jour. Sci., 3d ser., vol. 39, p. 83.

Founded on a fragmentary maxillary and premaxillary from the Judith River beds of Montana. These remains may very well pertain to some one of the species of Ceratopsidæ previously described. It can not certainly be determined whether they belong to *Ceratops* or to *Monoclonius*. Owing to the uncharacteristic nature of the type material, Marsh was unable to properly define the species, and it would be better to abandon it as a nomen nudum.

Besides the above-mentioned genera and species of Ceratopsidæ based on material from the Judith River beds there remain to be considered a number of others erroneously referred by some authors to this family.

STEGOCERAS VALIDUS Lambe.

Stegoceras validus Lambe, 1902, Cont. Canadian Palæont., vol. 3, pt. 2, p. 68, Pl. XXI.

This species is based on two anomalous bones from the Judith River beds of Canada. Although both these elements were referred by Lambe to a single species which he placed in the Ceratopsidæ, it is evident upon examination that they pertain to two different species and belong to another family. Lambe says of these elements: "It is probable that these bones were situated in the median line of the head, in advance of the nasals." It seems more probable, after a careful study of them, that they represent the roof of the brain case and the frontal region of the skull of some unknown reptile. For the exact determination of their homologies and the nature of the reptile to which they belonged we must await the discovery of more complete material.

MONOSPONDYLUS GIGAS Cope.

Monospondylus gigas Cope, 1892, Am. Naturalist, vol. 26, p. 757.

This species is based on two detached vertebral centra from the Cretaceous of South Dakota, referred by Cope to the Ceratopsidæ, but now known to pertain to the Theropoda. The present genus and species are referred to in this connection on account of their having been erroneously included by Osborn[a] in his list of genera and species from the Cretaceous of Montana. In showing these vertebræ to the writer Cope stated definitely that they were from the Laramie of South Dakota.

CLAORHYNCHUS TRIHEDRUS Cope.

Claorhynchus trihedrus Cope, 1892, Am. Naturalist, vol. 26, p. 757.

This species is based on a rostral and predentary presumably from the Laramie of South Dakota, although it is included by Osborn in his list from Montana. It has been referred by Cope to the Ceratopsidæ, but the parts described differ materially from the same elements in any known member of that family. From Cope's description they would appear to resemble more nearly the predentary and premaxillary of some member of the Trachodontidæ. The types are not accessible and their nature and relations can at present only be judged by the description given by Cope. Unfortunately Cope omitted to state where they were found and nothing is positively known concerning either their geographic or their stratigraphic position.

ORNITHOPODA.

TRACHODONTIDÆ.

TRACHODON Leidy.

This genus is perhaps more abundant than any other dinosaurian genus of the Judith River beds. Altogether five or six species, more or less distinct, have been described, while an equal number of species have been referred to other genera, some of which may prove to belong to *Trachodon*. Unfortunately the genus *Trachodon* and its included species, as well as the allied genera and species from the Judith River beds, are all based on such fragmentary material as to render their identification uncertain.

TRACHODON MIRABILIS Leidy.

Trachodon mirabilis Leidy, 1857, Proc. Acad. Nat. Sci. Philadelphia, 1856, p. 72.

Leidy states that this species is "founded upon specimens of teeth, generally very much worn and in a fragmentary condition." Although the trachodonts are easily distinguishable by their teeth from the

[a] Cont. Canadian Palæont., vol. 3, pt. 2, 1902, p. 15.

other Dinosauria of these beds, it is scarcely possible to identify the various species of this genus or the genera of the family from the teeth alone, although Lambe[a] has ventured to do so. The type of the present species was from the Judith River beds of Montana.

TRACHODON BREVICEPS (Marsh.)

Hadrosaurus breviceps Marsh, 1889, Am. Jour. Sci., 3d ser., vol. 37, p. 335.

This species is founded on a portion of right maxillary, with teeth in an admirable state of preservation. The label accompanying the specimen states that it is from the Bearpaw Mountains. There is no doubt, therefore, that it is from the Judith River beds. In form and general character the teeth resemble very closely those of *Trachodon selwyni* Lambe from the Judith River beds of Canada, as will be seen by a comparison of the figures published by Marsh and Lambe.

TRACHODON SELWYNI Lambe.

Trachodon selwyni Lambe, 1902, Cont. Canadian Palæont., vol. 3, pt. 2, p. 69, Pl. III.

This species is founded "principally on the evidence of teeth," distinguished "from those of *T. mirabilis* Leidy in being rounded oval above instead of terminating in a point." As stated above, in pattern and size the teeth of the present species as figured by Lambe agree very well with those of the type of *T. breviceps*, from the same beds in Montana as figured by Marsh, and it is quite possible that the present species is a synonym of *T. breviceps*.

TRACHODON MARGINATUS Lambe.

Trachodon marginatus Lambe, 1902, Cont. Canadian Palæont., vol. 3, pt. 2, p. 71, Pls. III–X.

This species is based on numerous teeth and remains of the skeleton representing almost all the different elements, for the most part found dissociated in the Judith River beds of Canada. That this species is based on material pertaining not only to different individuals, but to different species, genera, families, and even orders, is clear from a reference to Lambe's figures and descriptions. The ischium figured on Pl. X of his memoir as pertaining to the present species has nothing to do with the present genus, but is the ischium of some member of the Theropoda.

Of the abundant material figured and described by Lambe as belonging to this species, none of it has been designated as the type, and the identification of the species might best be considered as resting upon dental characters alone. On page 77 of his memoir Lambe distinguishes this species by the teeth, which he says are "rounded above, with a marginal sculpture."

[a] Cont. Canadian Palæont., vol. 3, pt. 2, 1902, p. 77.

TRACHODON ALTIDENS Lambe.

Trachodon altidens Lambe, 1902, Cont. Canadian Palæont., vol. 3, pt. 2, p. 76, Pl. IV.

This species is founded on a left maxilla with the teeth from the Judith River beds of Canada. Distinguished by the small, narrow, elongate teeth "beautifully marked for a short distance above the apex of the crown, on the raised edges of the outer enameled face by a few obliquely placed, transversely elongated embossments." The present species appears to represent one of the smaller members of the genus.

PTEROPELYX GRALLIPES Cope.

Pteropelyx grallipes Cope, 1889, Am. Naturalist, vol. 23, p. 904.

This species is based on a considerable portion of a skeleton without skull or teeth, from the Judith River beds of Montana. Distinguished from the preceding genus and species by its more slender proportions, pubis coössified with ischium, four digits in pes, and probably more elongate fore limbs.

Lambe[a] has distinguished the various species of *Trachodon* and *Pteropelyx* as follows:

Comparative table of teeth of species of Trachodon and Pteropelyx.

Trachodon mirabilis Leidy	Teeth pointed above; margins smooth.
Trachodon (Pteropelyx) selwyni Lambe.	Teeth rounded oval above; margins smooth or with the faintest indications of oblique transverse striæ.
Trachodon (Pteropelyx) marginatus Lambe.	Teeth rounded above; with a marginal sculpture.
Pteropelyx grallipes Cope	Teeth rounded above; with a border sculpture.
Trachodon (Pteropelyx) altidens Lambe.	Teeth of small size, long in proportion to the breadth, and pointed above; with a border sculpture near the apex.

In this table Lambe has omitted *Trachodon breviceps* Marsh, which, as I have already remarked, is probably identical with *T. selwyni* Lambe. While in the Trachodontidae, the teeth from various parts of the jaw of the same individual vary greatly in the form and markings, and great care should be taken in determining or proposing species from teeth alone, the teeth have certain characters, such as have been pointed out by Lambe in the above table, by which they may, within certain limits at least, be distinguished specifically. Before accepting such dental characters as distinctive of the various species the cranial and skeletal features associated with each should be determined. If those species founded on dental characters alone are valid, such characters will doubtless prove to be supplemented by other characters.

[a] Cont. Canadian Palæont., vol. 3, pt. 2, p. 76, Pl. IV.

CIONODON (CINODON) Cope.

Cionodon (*Cinodon*) Cope, 1874, Bull. U. S. Geol. and Geog. Surv. Terr., vol. 1, no. 1, p. 10.

This genus is founded on detached teeth from the Laramie of northeastern Colorado. It was afterwards reported from the Judith River beds. It may be regarded as a genus based on insufficient material, and so poorly defined as to be indeterminable.

CIONODON STENOPSIS Cope.

Cionodon stenopsis Cope, 1875, Proc. Acad. Nat. Sci. Philadelphia, 1875, p. 9.

This species is based on a maxillary and teeth from the Judith River beds near Milk River in Canada. According to Cope it is distinguished by the absence of a longitudinal keel on the lower part of the crown. It is quite probable that the present species is neither generically nor specifically distinct from some of the species of *Trachodon* mentioned above.

DICLONIUS Cope.

Diclonius Cope 1876, Proc. Acad. Nat. Sci. Philadelphia, 1876, p. 253.

This genus and three species—*D. pentagonus*, *D. perangulatus*, and *D. calamarius*—were proposed by Cope from shed teeth found scattered throughout the Judith River beds of Montana. The genus should be, and has very generally been, considered as a synonym of *Trachodon*. From Cope's descriptions of the teeth referred by him to the various species mentioned above, it seems probable that more than one species were represented. In the absence of any figures, and considering the nature of the characters ascribed by Cope to the various species, it is doubtful if any of them are at present identifiable without access to the types, and since the latter seem no longer to be certainly determinable in the Cope collection, it would not be amiss to drop also the specific names referred to this genus.

AVES.

CONIORNIS ALTUS Marsh.

Coniornis altus Marsh, 1893, Am. Jour. Sci., 3d ser., vol. 45, p. 82.

A single bird has been described from these beds. It was referred to the present genus and species. The type consisted of the distal portion of a tibia found near the base of the Judith River beds on Dog Creek, Montana. According to Marsh, its affinities are with *Hesperornis*, a genus of toothed birds from the Niobrara chalk of Kansas.

MAMMALIA.

Thus far only two species of mammals have been described from the Judith River beds. These were referred to two genera, and both were described by Lambe from material collected by him in Canada.

PTILODUS PRIMÆVUS Lambe.

Ptilodus primævus Lambe, 1902, Cont. Canadian Palæont, vol. 3, pt. 2, p. 79, Pl. XV.

This species is based on a fragment of a mandible with a first molar and fourth premolar in place. It is clearly related to, but somewhat more primitive than, *Meniscoëssus conquistis* Cope[a] from the Laramie of South Dakota.

BOREODON MATUTINUS Lambe.

Boreodon matutinus Lambe, 1902, Cont. Canadian Palæont, vol. 3, pt. 2, p. 79, Pl. XV.

This species is founded on a single premolar from the Judith River beds of Canada, resembling in some respects the teeth referred by Marsh to the genus *Stagodon*[b] from the Laramie of Converse County, Wyo. The jaw shown here in fig. 1 was found in the Judith River beds on the north side of Milk River, about half a mile below Meili Coulee and directly north of the red butte mentioned on page 50. It was found in place in a lens of rather hard, cross-bedded sandstone. Associated with it were remains of *Trachodon* and turtles. It is provisionally referred to the present genus and species, although, from the absence of any teeth with which to make direct comparison, it is impossible to establish their identity.

FIG. 1.—Posterior portion of right ramus referred to *Boreodon matutinus* Lambe. *A*, external view; *B*, internal; *C*, posterior; *m*, masseteric fossa; *idf.*, inferior dental foramen. Natural size.

The jaw is extremely heavy. While the coronoid process is imperfect, it is sufficiently preserved to show that it was high and strong. The angle was inflected much as in modern marsupials. The masseteric fossa was deep. The inferior dental foramen is placed well back and opens far down on the floor of the inflected angle, as shown in fig. 1. There is no mylohoid or Meckelian groove. Unfortunately no teeth are preserved, though there are a number of alveoli. The appearance of these alveoli suggests that there was a last, small, tubercular, single-rooted molar preceded by a double-rooted molar of mod-

[a] Am. Naturalist, 1882, p. 830. [b] Am. Jour. Sci., 3d ser., vol. 43, 1892, pl. 8, figs. 4, 5.

erate dimensions, while the preceding or first molar, assuming that there were three and only three true molars, was the largest of the series, as is indicated by its posterior root, which is still in place in the alveolus. It is laterally compressed and has the surface marked by faint striæ similar to those seen on the root of the type of the species, though not shown in Lambe's figure. The jaw was broken through the anterior alveolus of this tooth, and that portion of the ramus anterior to this is wanting.

SUMMARY.

From the foregoing review of the known vertebrates from the Judith River beds it will be seen that, while the fauna is one of considerable diversity, most of the genera and species are at present known from such insufficient and fragmentary material that it has not been possible hitherto to properly define them. It thus happens that a considerable number of genera and species that have been proposed for remains from these beds are not now determinable, and owing to the scanty material upon which not a few of these were originally founded it is quite impossible to refer to these with any degree of certainty, subsequently discovered and more perfect material, and thereby to further define and describe them. This is true to a greater or lesser extent of all the Vertebrata of these beds, but it is especially applicable to the fishes, amphibians, and by far the larger portion of the reptiles, while the birds and mammals of Judith River times are at present known from such exceedingly scanty material as of themselves to offer almost no evidence of the character of the avian and mammalian life of those times. Our knowledge of the vertebrate fauna of these beds, now that their geographic distribution is known not to be so limited as had been previously supposed, will doubtless be greatly increased by more persistent collecting, aided by modern methods. At present, however, while we are in many cases unable to adequately define many of the genera and species, we know enough of the fauna as a whole to form a very good general idea of its character, and although we can not compare it closely with the related faunas of other horizons, yet enough is known of it to establish certain similarities and dissimilarities. These are especially pronounced in certain groups like the Ceratopsidæ and the Trachodontidæ, where there was already a high degree of specialization and where many of the different species are known from fairly satisfactory material.

When considered in its entirety, the vertebrate fauna of these beds is remarkably similar to, though distinctly more primitive than, that of the Laramie. Almost or quite all of the Laramie types of vertebrates are present, though, as a rule, they are represented by smaller and more primitive forms. The similarity between this fauna and that of the Laramie contrasts strongly with the great dissimilarity between the

vertebrates of the Judith River and those of the Atlantosaurus beds, the next older fresh-water horizon in this region, containing also a rich and varied vertebrate fauna, but quite distinct from that of the beds in question.

The Dinosauria were the predominant vertebrates in Judith River times, and they, of all the vertebrates of these beds, afford the best basis for a comparison of the fauna of these deposits with that of the Laramie above and the Jurassic below. The great group of Sauropoda, which formed so conspicuous a feature of the animal life at the close of the Jurassic and the beginning of the Cretaceous, is entirely wanting. Among the Predentata the Stegosauria, which had formed so striking a feature among the Jurassic dinosaurs, have almost or quite disappeared and are replaced entirely by the quadrupedal Ceratopsidæ and the bipedal Trachodontidæ. No unmistakable repesentative of the Stegosauria is certainly known from the Judith River beds. *Palæoscincus*, referred to this suborder chiefly on the evidence of teeth alone, may or may not pertain to the Stegosauria; while *Stereocephalus* appears to have been founded on material belonging in part to the Crocodilia and in part to the Dinosauria. No evidence has as yet been produced to show that the large pointed shields described and figured by Lambe as pertaining to this genus may not have belonged to some member of the Theropoda or to the Ceratopsidæ. That they really belonged to one or the other of these is most likely, since very similar plates have been met with in the Laramie also. No vertebræ or shield plates like those known to have belonged to *Stegosaurus* are known from the Judith River beds.

The Trachodontidæ had already attained to considerable diversity in Judith River times. Indeed, they appear to have been more abundant, as regards both numbers of individuals and genera and species, than they were in the Laramie. Judging from the rather meager material at hand for comparison they were, however, somewhat less specialized, as is evidenced by such characters as the presence of four digits in the pes of *Pteropelyx* and the complement of teeth, which in the later Laramie forms seems to have been considerably greater than in the Judith River.

It is in the Ceratopsidæ more than in any other group that we are at present able to contrast the Judith River and Laramie forms. The chief differences are noticeable in the skull, and more especially in the structure of the parietal crest and the comparative size of the supraorbital and frontal horn cores. In the Laramie the supraorbital horn cores are always much larger than the nasal and the latter are frequently rudimentary, while in the Judith River beds conditions just the reverse prevail. In the Laramie the huge parietal fontanelles so common in the forms from the Judith River beds are known only in the single rare genus *Torosaurus*. There is some evidence also that *the teeth in some* of the Judith River forms are only in the process of

assuming that method of replacement which is common in later representatives of the group, and by means of which the single root of the embryo tooth early becomes bifurcated. The primitive nature of the Judith River Ceratopsidæ, as compared with the Laramie, is especially seen in *the smaller size of the individuals, the less perfectly developed armature of the skull, and the imperfectly developed parietal crest.*

So little is at present actually known of the Theropoda of either the Laramie or the Judith River beds that it is quite impossible to make anything like an adequate comparison between them. The group, however, is represented in both formations by quite similar forms, though differing perhaps both generically and specifically. The Theropoda in the Judith River beds show much greater diversity than do those of the Jurassic, and judging from the remains available they represent quite different types.

Although much is desired in the way of better material before we shall be able to determine, even approximately, the character of the vertebrate fauna of the Judith River beds, enough is already known to suggest its diversity and to show that the fauna is similar to that of the Laramie and different from that of the Jurassic. The long period of time which had elapsed between the close of the deposition of the Atlantosaurus beds and the beginning of the Judith River was sufficient to accomplish a complete revolution in the vertebrate fauna of that region, though most of the later forms are clearly descended from the earlier. Scarcely a single vertebrate of strictly Jurassic type is found in this fauna, for, as mentioned above, *Stereocephalus* Lambe, referred by that author and by Osborn to the Stegosauria, appears to have been founded on a composite type containing remains pertaining both to the Crocodilia and to the Dinosauria. The Dinosauria are not distinguishable from remains from the Laramie at present referred to the Ceratopsia, and the Crocodilia represent a group of crocodiles at present only known from the Judith River beds.

Briefly, the Judith River fauna, it is clear, is descended from the Jurassic and is the direct ancestor of the Laramie. Its relations with the former are not close, and several groups are absent in the one which are present in the other. Its relations with the Laramie are much closer, as should be expected, considering the stratigraphic position. With one or two possible exceptions all the families represented in either of these two later deposits are present also in the other. Although several genera and species now appear to be common to both these formations, it is probable that when more perfect material is available they will be found, in most instances, to be quite distinct, though some pertaining to more persistent types may prove to be identical. In every case where any group of the fauna has been studied from sufficient material it has been found to be represented by distinctly older and more primitive types than the related forms from the Laramie.

INVERTEBRATE FAUNA.

By T. W. STANTON.

The invertebrate fossils of the Judith River beds have nearly all been adequately described and illustrated by Meek,[a] White,[b] and Whiteaves[c] in previous publications. For the present purpose, therefore, it will be sufficient to describe and illustrate a few new species and to give an annotated list of the others, with references to good figures. The systematic list will be followed by a brief discussion of the character and relationships of the fauna and of the evidence it affords as to the conditions under which the formation was deposited.

PELECYPODA.

OSTREA SUBTRIGONALIS Evans and Shumard.

Ostrea subtrigonalis Meek, 1876, Rept. U. S. Geol. Surv. Terr., vol. 9, p. 510, Pl. XL, figs. 1a–1d.

The species was originally described from the vicinity of Owl Butte, between Grand and Moreau rivers, South Dakota, from beds that are now supposed to belong to the Laramie. From the fact that the types have never been figured and that no one has since studied them or other material from the type area, it may be questionable whether the Judith River form which Meek described under the same name is really identical. Whatever the final decision on that point may be, the form figured by Meek is the most abundant and widely distributed of the Judith River invertebrates. In the exposures near the Missouri on Dog Creek, Birch Creek, and Cow Creek there is a bed from 1 to 2 feet in thickness, at or very near the top of the formation, almost entirely composed of the shells of this species, with local accumulations of *Corbicula cytheriformis*, and less abundant specimens of *Corbula subtrigonalis*, *Anomia gryphorhynchus*, and *Goniobasis convexa*. The

[a] Invertebrate Cretaceous and Tertiary fossils of the upper Missouri country: Rept. U. S. Geol. Surv. Terr., vol. 9, 1876, pp. 509–592, pls. 42–43.

[b] Review of the nonmarine fossil Mollusca of North America: Third Ann. Rept. U. S. Geol. Survey, 1883, pp. 411–550.

[c] Report on the Invertebrata of the Laramie and Cretaceous rocks of the vicinity of the Bow and Belly rivers and adjacent localities in the Northwest Territory: Cont. Canadian Palæont., vol. 1, pt. I, 1885. The Belly River [Judith River] species are described on pp. 55–77.

same brackish-water fauna has a similar development at this upper horizon on Milk River in the neighborhood of Havre, especially near the mouth of Beaver Creek, 2 to 3 miles west of Havre, and at the head of Supenaw Coulee, on the north side of the river, 5 or 6 miles farther west. *Ostrea subtrigonalis* is reported by Whiteaves from about the same horizon at the mouth of St. Mary River and in Milk River Ridge, Canada, where the bed is referred to the "base of the shales of the Fort Pierre group."

Ostrea subtrigonalis also occurs in the upper part of the Claggett formation, on the north side of Milk River 4 miles west of Havre, Mont., and near Pendant d'Oreille, Canada, at both places associated with *O. glabra*, with which it seems to be connected by intermediate forms. It is reported from the lower Laramie and from the "Belly River" beds at several localities in Alberta and Assiniboia.

OSTREA GLABRA Meek and Hayden.

Ostrea glabra Meek, 1876, Rept. U. S. Geol. Surv. Terr., vol. 9, p. 509, Pl. XL, figs. 2a–2d.

Ostrea glabra White, 1883, Third Ann. Rept. U. S. Geol. Survey, p. 421, Pls. IX–XI.

The types of the species came from near the mouth of Judith River, but whether they occurred there in the Judith River beds or in the Claggett formation is not certainly known. In the present collection it was obtained from the upper part of the Claggett formation on Milk River 4 miles west of Havre, Mont., and in the neighborhood of Pendant d'Oreille, Assiniboia, and at the latter locality in the basal beds of the Judith River. Whiteaves reports it from several localities in the Canadian "Belly River" beds. It is also a very common species of the Laramie at many localities in the United States as well as in Canada, and apparently the same species occurs at several horizons in the Montana group.

ANOMIA GRYPHORHYNCHUS Meek.

Anomia gryphorhynchus White, 1883, Third Ann. Rept. U. S. Geol. Survey, p. 422, Pl. XII, figs. 12–15.

The original locality is Point of Rocks, Wyoming, where the species occurs in a horizon now known to be in the Montana group, and probably not far from the horizon of the Judith River beds. It has also been recognized at Black Buttes, Wyoming; Crow Creek, Colorado, and various other localities in the Laramie. The species is not uncommon associated with *Ostrea subtrigonalis* near the top of the Judith River beds on Cow Creek, and near Havre, Mont., and at the base of the same formation or in the upper layers of the Claggett near Pendant d'Oreille, Assiniboia. It shows considerable variation in size and in the convexity of the upper valve.

ANOMIA MICRONEMA Meek.

Anomia micronema White, 1883, Third Ann. Rept. U. S. Geol. Survey, p. 422, Pl. XII, figs. 6–11.

Anomia micronema Whiteaves, 1885, Cont. Canadian Palæont., vol. 1, p. 64.

This common Laramie species has been reported by Whiteaves from the Belly River beds of South Saskatchewan, half a mile below the forks of Bow and Belly rivers.

AVICULA NEBRASCANA Evans and Shumard.

Pteria (Oxytoma) nebrascana Meek, 1876, Rept. U. S. Geol. Surv. Terr., vol. 9, p. 34, Pl. XVI, figs. 5a, 5b, and Pl. XXVIII, fig. 11.

Pteria (Oxytoma) nebrascana Whiteaves, 1885, Cont. Canadian Palæont., vol. 1, p. 56.

Whiteaves reports this species from the "Belly River" beds in Milk River Ridge, Alberta. It is a common form in both the Claggett and the Bearpaw formations, and may therefore be expected in the Judith River beds wherever a marine stratum occurs.

MYTILUS SUBARCUATUS Meek and Hayden.

Mytilus subarcuatus Meek, 1876, Rept. U. S. Geol. Surv. Terr., vol. 9, p. 69, Pl XXXVIII, figs. 2a, 2b.

Mytilus subarcuatus Whiteaves, 1885, Cont. Canadian Palæont., vol. 1, p. 56.

The type is from Dog Creek, Montana, probably in the Claggett formation. Whiteaves reports it from the "Belly River" beds on South Saskatchewan River 8 miles below Red Deer River, and our collections contain a single specimen doubtfully referred to the species from the top of the Judith River beds in Meili Coulee, 4 miles west of Havre, Mont.

MODIOLA sp.

Fragments of a species with rather coarse radiating sculpture were collected from the lower part of the formation on Milk River, near Pendant d'Oreille, Assiniboia, and from the upper brackish-water bed on Cow Creek, Montana, 13 miles above its mouth.

CRENELLA PARVULA Whiteaves.

Crenella parvula Whiteaves, 1885, Cont. Canadian Palæont., vol. 1, p. 57, Pl. IX, fig. 1.

This species is known only from strata referred to the "Belly River" beds in Milk River Ridge, Alberta.

NUCULA sp.

Imperfect specimens of an undetermined species of *Nucula* were seen in a bed of friable sandstone containing other marine fossils on Cow Creek, Montana, about 7 miles above its mouth. The horizon is about 150 feet below the top of the Judith River beds.

LEDA sp.

An imperfect specimen of a large species, probably undescribed, was collected on Cow Creek at the locality and horizon last mentioned.

ANODONTA PROPATORIS White.

Anodonta propatoris White, 1883, Third Ann. Rept. U. S. Geol. Survey, p. 429, Pl. XIX, figs. 6–9.

The types are from Judith River beds on Dog Creek and Birch Creek, Montana. This species is represented in our collections from the neighborhood of the original localities and also from Cow Creek, Willow Creek, and near Havre, Mont., and somewhat doubtfully from Sage Creek, Assiniboia. Whiteaves reports the species, with some doubt as to identification, from many Canadian localities. It seems to be confined to the Judith River beds, and ranges throughout the whole formation except the brackish-water and marine layers. It is usually preserved in the form of casts and no perfect specimens are known.

ANODONTA PARALLELA White?

Anodonta parallela White, 1883, Third Ann. Rept. U. S. Geol Survey, p. 429, Pl. XIX, fig. 5.

Whiteaves has reported one doubtful specimen of this Laramie species from the "Belly River" beds on the South Saskatchewan 1 mile below the mouth of Bow River.

UNIO SUBSPATULATUS Meek and Hayden.

Pl. XIII, fig. 1.

Unio subspatulatus Meek, 1876, Rept. U. S. Geol. Surv. Terr., vol. 9, p. 518, Pl. XLI, figs. 1*a*, 1*b*.

The type from near the mouth of Judith River has the outer surface exfoliated so that the beak sculpture is not retained and the beaks are made to appear somewhat nearer the anterior end than they actually are. On Milk River 2 miles below Pendant d'Oreille, Assiniboia, Mr. Hatcher collected many well-preserved specimens of a *Unio* that seems to be referable to this species from a stratum containing *Corbula*, *Corbicula*, and *Modiola*, near the base of the Judith River beds. Some imperfect specimens were collected at the mouth of Meili Coulee, on the north side of Milk River 4 miles west of Havre, Mont.

It is a rather slender, compressed shell, with nearly terminal, inconspicuous beaks and narrowed posterior end. The umbonal region is marked by a few distinct, undulating, concentric ridges, and the posterior umbonal slope bears two sharply elevated radiating lines that fade out about an inch from the beak. The shell is rather thin, and the teeth are correspondingly light.

Similar beak sculpture is found in several Cretaceous species of *Unio*, such as *U. vetustus*, *U. priscus*, etc., but the general form and proportions of the shell are different. It is a much lighter, less convex shell, with more nearly terminal beaks than *Unio danæ* and *U. deweyanus*, with which it has sometimes been supposed to be identical.

UNIO PRISCUS Meek and Hayden?

Pl. XII, fig 1.

Unio priscus Meek, 1876, Rept. U. S. Geol. Surv. Terr., vol. 9, p. 516, Pl. XLIII, figs. 8*a*–8*d*.

The type of this species is from the Yellowstone, 40 miles above its mouth, and presumably from beds of Laramie age. Meek also figured small specimens from Judith River, but it is somewhat doubtful whether they are really identical with the Yellowstone form which is represented in the National Museum collection by the single crushed specimen. All the specimens have an elongate form and beaks with strong concentric wrinkles, but those from Judith River and from the same formation on Milk River at Pendant d'Oreille, Assiniboia, and at a locality 5 miles south of Wild Horse Lake, on the Canadian boundary, have the posterior end somewhat broader and other slight differences in outline that may have specific or varietal importance. The specimen figured is from the locality last named.

UNIO PRISCUS var. ABBREVIATUS n. var.

Pl. XII, figs. 2–4.

This variety has the general aspect and sculpture of *U. priscus*, with the strong concentric wrinkles on the beaks and two elevated radiating lines on the posterior umbonal slope, but it differs in having the posterior end relatively much shorter and somewhat broader, and it is apparently somewhat more convex. The shell is rather thin and the hinge teeth are light. The specimens figured are from Milk River, about 5 miles south of Wild Horse Lake.

UNIO DANÆ Meek and Hayden.

Unio danæ Meek, 1876, Rept. U. S. Geol. Surv. Terr., vol. 9, p. 517, Pl. XLI, figs. 3*a*–3*c*.

Unio deweyanus Meek, 1876, Rept. U. S. Geol. Surv. Terr., vol 9, p. 519, Pl. XLI, figs. 2*a*–2*c*.

The specimens described under the two names cited above all came from near Judith, Mont., and the differences on which the two species are based are due to the state of preservation rather than actual specific characteristics. None of the types shows all of the specific features fully, but those of *U. danæ* give a better idea of the outline and general proportions, while those of *U. deweyanus* show part of the surface and details of the hinge, though giving an erroneous impression concerning the form. Our collections contain many specimens evidently belonging to one species, some of which agree with one of these types and some with the other. The species attains a much larger size than the types, and apparently Meek was right in describing the beaks as unsculptured, in this respect differing from the form

which I have identified with *Unio subspatulatus*. We collected it on Sage Creek, Assiniboia; on Milk River, near Havre; on Cow Creek, Dog Creek, and at other localities in the original Judith River area. Apparently the same species, or if not, a closely related one that can not be separated with the imperfect material at hand, occurs in the Laramie at Black Buttes and on Lance Creek, Wyoming, near the mouth of the Yellowstone, and elsewhere in Montana. It has also been reported from the Laramie of Alberta.

UNIO SUPENAWENSIS n. sp.

Pl. XIII, figs. 2 and 3.

Shell of medium size, obliquely subovate in outline, with relatively thick test and broad hinge plate; beaks very prominent, slightly incurved, very near the anterior end of the shell, and sculptured with distinct concentric wrinkles; the rest of the surface showing only ordinary lines of growth and very faint radiating striæ, which probably are not visible except when the actual surface is slightly exfoliated; dorsal and basal margins forming very gentle regular curves; anterior margin slightly excavated above in front of the beak and broadly rounded below; posterior end somewhat narrowly rounded; shell very gently convex in the umbonal and median portions, but abruptly descending toward the front and dorsal margins; cardinal teeth large, very irregular in form, and strongly corrugated; posterior lateral well developed, elongate.

Length of type, about 65 mm; height, about 55 mm; convexity of single valve, 22 mm.

The only Cretaceous species at all resembling this are *Unio propheticus* White and *U. proavitus* White, both of which were described from the Laramie at Black Buttes, Wyoming, and may well be considered as descendants of *U. supenawensis*. The resemblance is closer with *U. propheticus*, which is slightly smaller, with beaks nearer the anterior end, a more distinctly flattened band extending from the beak to the middle of the basal margin, more broadly rounded posterior end, and straighter basal margin.

Locality.—The types were found near the top of the Judith River beds at the head of Supenaw Coulee, about 10 miles northwest of Havre, Mont., where the species is common. Another specimen was obtained from near the same horizon on the north side of Milk River opposite Havre.

UNIO CRYPTORHYNCHUS White.

Unio cryptorhynchus White, 1883, Third Ann. Rept. U. S. Geol. Survey, p. 431, Pl. XIV, figs. 6, 7.

The types are from Dog Creek, Montana, and the species has been doubtfully identified in the Laramie at Black Buttes, Wyoming.

UNIO SENECTUS White.

Unio senectus White, 1883, Third Ann. Rept. U. S. Geol. Survey, p. 432, Pl. XIX, figs. 1, 2.

From Dog Creek, Montana, and also reported by Whiteaves from the South Saskatchewan near the mouth of Bow River.

UNIO PRIMAEVUS White.

Unio primaevus White, 1883, Third Ann. Rept. U. S. Geol. Survey, p. 432, Pl. XIV, figs. 4, 5.

From Judith River beds near Cow Island, Montana. Also reported by Whiteaves from branch of east fork of Milk River, near the Canadian boundary. It occurs in our collections from Cow Creek and from Milk River 5 miles south of Wild Horse Lake.

Some of the specimens apparently belonging to this species are very much larger and more elongate than the type. It is probable that the two specimens figured by White represent two species, and if so, the smaller one, whose outer surface is figured, should be considered the type. The exterior of the other specimen is in a very poor state of preservation, so that its specific characters are not clearly determinable. It may possibly be the same as *U. priscus* var. *abbreviatus*, described above.

UNIO CONSUETUS Whiteaves.

Unio consuetus Whiteaves, 1885, Cont. Canadian Palæont., vol. 1, p. 59, Pl. IX, figs. 4, 4*a*.

Described from the "Belly River" beds of Alberta. Somewhat doubtfully identified in our collections from the Judith River beds at Willow Creek, Montana.

UNIO SUPRAGIBBOSUS Whiteaves.

Unio supragibbosus Whiteaves, 1885, Cont. Canadian Palæont., vol. 1, p. 66, Pl. X, fig. 1.

Types from South Saskatchewan near mouth of Bow River. Represented in our collection from lower part of Judith River beds on Milk River 2 miles below Pendant d'Oreille, Assiniboia, associated with *U. subspatulatus*.

UNIO sp.

There are several other species of Unio represented in our collections by material too imperfect for satisfactory specific description. It is therefore thought better to await more complete collections. Several of the species already described, from the formation, are so imperfectly known that it is almost impossible to identify them, even by direct comparison with the types.

SPHÆRIUM PLANUM Meek and Hayden.

Sphærium planum, Meek, 1876, Rept. U. S. Geol. Surv. Terr., vol. 9, p. 526, Pl. XLIII, figs. 6*a*, 6*b*.

This is one of the most common of the Judith River fresh-water species, occurring at many localities in the original area on Dog Creek, Birch Creek, and Cow Creek, and on Milk River from Havre to the Canadian boundary. The types came from near Grand Island, on the Missouri, below the mouth of Cow Creek, but they were at first erroneously reported to have come from near Grand River, Nebraska. The species attains a size considerably larger than the figured type. A similar but not identical form occurs in the Laramie of Converse County, Wyo.

SPHÆRIUM RECTICARDINALE Meek and Hayden.

Sphærium recticardinale Meek, 1876, Rept. U. S. Geol. Surv. Terr., vol. 9, p. 527, Pl. XLIII, figs. 3*a*, 3*b*.

The types are from the same locality as the preceding, and the species, though not so abundant, also occurs sparingly at nearly all the localities where *S. planum* is found. Large specimens are nearly half an inch in length.

SPHÆRIUM FORMOSUM Meek and Hayden?

Sphærium formosum? Whiteaves, 1885, Cont. Canadian Palæont., vol. i, pp. 61 and 68, Pl. IX, fig. 3.

This form, from the Judith River beds of Alberta, is doubtfully referred to *S. formosum*, which was originally described from Laramie or Fort Union beds near the mouth of the Yellowstone. The Canadian shell may possibly be the young of one of the preceding species.

CORBICULA OCCIDENTALIS Meek and Hayden.

Corbicula occidentalis Meek, 1876, Rept. U. S. Geol. Surv. Terr., vol. 9, p. 521, Pl. XL, figs. 6*a*–6*c*.

This form originally described from the badlands of the Judith, is less abundant there than *C. cytheriformis*, with which it is associated, but on Milk River near Pendant d'Oreille, Assiniboia, it is very common near the base of the Judith River beds, where it is associated with specimens that are intermediate in character between these two nominal species. It was collected on Cow Creek and near the mouth of Birch Creek, Montana, and forms that are apparently not specifically separable occur in the Laramie of Wyoming and northwestern Colorado, as well as the "Western Laramie" of Canada.

CORBICULA CYTHERIFORMIS Meek and Hayden.

Corbicula cytheriformis Meek, 1876, Rept. U. S. Geol. Surv. Terr., vol. 9, p. 520, Pl. XL, figs. 5*a*–5*c*.

The remarks on the range and distribution of *C. occidentalis* apply to this form also. It is locally very abundant in the brackish-water

bed at the top of the Judith River on Cow Creek and near the mouth of Birch Creek, and it also occurs on Milk River 3 miles west of Havre. Forms that have been referred to the same species occur in the Montana group at Point of Rocks, Wyoming, and in the Laramie at Black Buttes, Wyoming, and at various points in Wyoming and Colorado, as well as in Alberta. The type of *Corbicula* represented by this and the preceding species may be said to range throughout the Upper Cretaceous, as similar forms are found in the Colorado group in Utah and in the Bear River formation in Wyoming.

TELLINA sp.

A single specimen of a medium sized *Tellina* was obtained from the marine stratum 150 feet below the top of the Judith River beds on Cow Creek, Montana, 7 miles above its mouth.

PANOPÆA SIMULATRIX Whiteaves.

Panopæa simulatrix Whiteaves, 1885, Cont. Canadian Palæont., vol. 1, p. 11, Pl. II fig. 2, 2*a*.

The types are reported from several localities in the "Western Laramie" area of Canada, but it is possible that some of those localities, if not all, are in the Judith River beds. We collected the species on Milk River 3 miles west of Havre, and on Cow Creek 13 miles above its mouth. In both cases it was associated with the brackish-water forms at the top of the formation.

LIOPISTHA (CYMELLA) UNDATA Meek and Hayden.

Liopistha (*Cymella*) *undata* Meek, 1876, Rept. U. S. Geol. Surv. Terr., vol. 9, p. 236, Pl. XXXIX, figs. 1*a*, 1*b*.

Originally described from beds now known to belong to the Claggett formation near the mouth of the Judith, the species is also of common occurrence in the Bearpaw shales, and it was found in the marine stratum 150 feet below the top of the Judith River beds on Cow Creek 7 miles above its mouth.

MACTRA WARRENANA Meek and Hayden?

Mactra (*Cymbophora*) *warrenana* Meek, 1876, Rept. U. S. Geol. Surv. Terr., vol. 9, p. 208, Pl. XXX, figs. 7*a*–7*d*.

A single specimen from the locality and horizon last mentioned is doubtfully referred to this Fox Hill species.

MACTRA (CYMBOPHORA) ALTA Meek and Hayden.

Mactra (*Cymbophora*) *alta* Meek, 1876, Rept. U. S. Geol. Surv. Terr., vol. 9, p. 210, Pl. XXXVII, figs. 2*a*, 2*b*; Whiteaves, 1885, Cont. Canadian Palæont., vol. 1, p. 62.

Whiteaves reports this species from the Judith River beds in the Milk River Ridge, Alberta. The occurrence may be in a local marine facies of the formation like that mentioned on Cow Creek, or it may be in the top of the Eagle formation, where it normally occurs.

CORBULA SUBTRIGONALIS Meek and Hayden.

Corbula subtrigonalis Meek, 1876, Rept. U. S. Geol. Surv. Terr., vol. 9, p. 529, Pl. XL, figs. 3*a*, 3*b*.

This species was first described from the brackish-water bed at the top of the Judith River formation in the typical area. It has since been recognized at many localities in the Western States and Canada, from the Benton formation to the Laramie. In our collections it was found most abundantly in the lower part of the Judith River near Pendant d'Oreille, Assiniboia, but it occurs sparingly wherever the brackish-water strata are found.

At the locality on Cow Creek, 13 miles above its mouth, a greatly elongated variety occurs with the typical form.

CORBULA PERUNDATA Meek and Hayden.

Corbula perundata Meek, 1876, Rept. U. S. Geol. Surv. Terr., vol. 9, p. 528, Pl. XL, figs. 4*a*–4*d*.

Originally described from the same locality as the preceding, it also occurs with it at many localities on Milk River from Havre, Mont., to Pendant d'Oreille, Assiniboia, and elsewhere in that territory and Alberta.

GASTEROPODA.

NERITINA sp.

Velatella baptista (White) Whiteaves, 1885, Cont. Canadian Palæont., vol. 1, p. 73.
Not *Neritina* (*Velatella*) *baptista* White, 1880, Twelfth Ann. Rept. U. S. Geol. and Geog. Surv. Terr., p. 89, Pl. XXIX, figs. 6*a*, 6*b*.

Specimens from Milk River near Pendant d'Oreille, in the neighborhood of some of Whiteaves's localities, on direct comparison with the types of *Neritina baptista* from the Laramie at Black Buttes, Wyoming, prove to be different in both form and color pattern, but the material in hand is not sufficient for specific description.

LUNATIA sp.

A small specimen of an undetermined species was collected with the other marine fossils 150 feet below the top of the Judith River formation on Cow Creek 7 miles above its mouth.

VIVIPARUS CONRADI Meek and Hayden.

Viviparus conradi Meek, 1876, Rept. U. S. Geol. Surv. Terr., vol. 9, p. 597, Pl. XLII, figs. 15*a*–15*d*.

This species was originally described from near the mouth of Judith River. We found it locally abundant near the top of the Judith River formation on Cow Creek, and Whiteaves reports it from a number of localities in Canada. It has been erroneously reported to occur in the Bear River formation.

VIVIPARUS sp.

Imperfect specimens representing at least two or three species were found at a number of localities on the Missouri and on Milk River, but they were too much distorted and crushed for specific description. These forms seem to be closely allied to Laramie species, but apparently not identical with them.

CAMPELOMA VETULA Meek and Hayden.

Campeloma vetula Meek, 1876, Rept. U. S. Geol. Surv. Terr., vol. 9, p. 587, Pl. XLIV, figs. 14*a*, 14*b*.

Described from the Judith River area. We found it most abundant and beautifully preserved in the upper part of the Judith River formation near the head of Supenaw Coulée, about 10 miles northwest of Havre. The specimens obtained here are clearly referable to *C. vetula*, though they are also very much like the typical form of *C. multilineata* from the Laramie. The slight differences pointed out by Meek hold good, except that some of our specimens are slightly unbilicated, and these differences are probably of specific importance in spite of the fact that specimens not in a good state of preservation may be difficult to classify. The common Laramie form of *C. multilineata* with shouldered whorls is very distinct. The Laramie specimens from Black Buttes, Wyoming, and elsewhere, that have been referred to *C. vetula*, so far as I have been able to reexamine them, are too imperfect for positive identification, and may well belong to *C. multilineata*.

At least a part of the specimens from the Canadian Judith River beds referred to *C. multilineata* by Whiteaves probably belong to *C. vetula*.

CAMPELOMA MULTILINEATA Meek and Hayden.

Campeloma multilineata Whiteaves, 1885, Cont. Canadian Palæont., vol. 1, p. 77.

See remarks under *C. vetula*, above. No specimens referable to this species have been found in the Judith River beds of Montana, but it is one of the most common Laramie species, ranging probably as high as the Fort Union.

CAMPELOMA PRODUCTA White.

Campeloma producta White, 1883, Third Ann. Rept. U. S. Geol. Surv., p. 469, Pl. XXVI, figs. 21–27; Whiteaves, 1885, Cont. Canadian Palæont., vol. 4, pp. 24, 28, 77.

This is also a Laramie species that has not been found in the Judith River beds of the United States, but has been reported by Whiteaves from both the Laramie and the Judith River of Canada.

VALVATA? MONTANAENSIS Meek.

Valvata? montanaensis Meek, 1876, Rept. U. S. Geol. Surv. Terr., vol. 9, p. 591, text figs. 81–83.

Described from mouth of Judith River. Represented in our collections from two localities on Cow Creek.

HYDROBIA SUBCONICA Meek.

Hydrobia subconica Meek, 1876, Rept. U. S. Geol. Surv. Terr., vol. 9, p. 573, text fig. 77.

Mouth of Judith River.

HYDROBIA SUBCYLINDRACEA Whiteaves.

Hydrobia subcylindracea Whiteaves, 1885, Cont. Canadian Palæont., vol. 1, p. 75, Pl. X, fig. 8.

Type from Belly River east of Driftwood Bend. Whiteaves also reports the species from Milk River near Pakowki Coulée, and we collected it at Pendant d'Oreille, near the latter locality, where it was associated with *Corbula subtrigonalis*, *C. perundata*, and *Rhytophorus glaber*, near the base of the Judith River beds.

MELANIA? WHITEAVESI n. sp.

Pl. XIII, fig. 5.

Melania insculpta (Meek) Whiteaves, 1885, Cont. Canadian Palæont., vol. 1, p. 73, Pl. X, fig. 6.

Not *Melania insculpta* Meek, 1873, Sixth Ann. Rept. U. S. Geol. Surv. Terr., p. 515.

Shell of moderate size and rather robust form; whorls moderately convex, with the suture between them deeply impressed; surface marked by rather narrow, elevated, revolving striæ, of which about six are visible on the spire, and by broader, more distant, curved ribs, which are more or less nodose at the intersections with the revolving lines. There are fifteen ribs on the last whorl of the specimen figured, which is considerably more strongly sculptured than the average.

Height, with apex restored, about 40 mm.; breadth, 13 mm.

The specimens studied show much variation in the strength of the sculpture, with every gradation from the nearly smooth forms like that figured by Whiteaves to the one illustrated here. The species differs from *M. insculpta* in the form of the whorls and in all the details of sculpture, both the ribs and the spiral lines being more distant and less regular.

Some of the more strongly sculptured specimens of *Goniobasis convexa* M. & H. approach this form rather closely, and it is probable that they are related. Both are always found associated with brackish-water or marine species. The figured specimen of *M. whiteavesi* was obtained from near the base of the Judith River beds on Milk River 6 miles

below Pendant d'Oreille, Assiniboia, and it was collected at several other localities near there, at one point ranging down into the top of the Claggett formation. Whiteaves reports it (under the name *M. insculpta*) from the same neighborhood, but his figured specimen is from the South Saskatchewan 6 miles below the mouth of Bow River.

GONIOBASIS CONVEXA Meek and Hayden.

Goniobasis convexa Meek, 1876, Rept. U. S. Geol. Surv. Terr., vol. 9, p. 562, text figs. 71, 72, and Pl. XLII, figs. 2*a*, 2*b*.

Described from mouth of Judith River. Represented in our collections from Milk River near Havre, associated with *Ostrea*, *Anomia*, and other brackish-water forms at the top of the Judith River beds.

GONIOBASIS CONVEXA var. IMPRESSA Meek and Hayden.

Goniobasis convexa var. *impressa* Meek, 1876, Rept. U. S. Geol. Surv. Terr., vol. 9, p. 563, Pl. XLII, figs. 2*c*, 2*d*.

Occurs with the preceding at the type locality and in the brackish-water bed at the top of the formation on Cow Creek.

GONIOBASIS SUBLÆVIS Meek and Hayden.

Goniobasis sublævis Meek, 1876, Rept. U. S. Geol. Surv. Terr., vol. 9, p. 567, Pl. XLII, figs. 5*a*, 5*b*.

Types from the fresh-water beds near the mouth of Judith River. Common on Cow Creek and Willow Creek, and along Milk River from Havre, Mont., to the Canadian boundary.

GONIOBASIS INVENUSTA Meek and Hayden.

Goniobasis invenusta Meek, 1876, Rept. U. S. Geol. Surv. Terr., vol. 9, p. 564, Pl. XLII, figs. 1*a*–1*c*.

Occurs with the preceding and is somewhat more abundant, being found at most localities where fresh-water fossils occur in the Judith River beds, as far north as Pendant d'Oreille, Assiniboia.

GONIOBASIS GRACILENTA Meek.

Goniobasis gracilenta Meek, 1876, Rept. U. S. Geol. Surv. Terr., vol. 9, p. 568, text fig. 74, and Pl. XLII, fig. 3.

This species was found at the mouth of Judith River. It has also been reported from the Laramie at a number of localities in Wyoming and Colorado, but the state of preservation of all these specimens, as well as of the types, is such that their specific identity is doubtful.

GONIOBASIS? OMITTA Meek and Hayden.

Goniobasis? omitta Meek, 1876, Rept. U. S. Geol. Surv. Terr., vol. 9, p. 568, Pl. XLII, figs. 4*a*–4*c*.

Mouth of Judith River.

GONIOBASIS ? SUBTORTUOSA Meek and Hayden.

Goniobasis ? subtortuosa Meek, 1876, Rept. U. S. Geol. Surv. Terr., vol. 9, p. 569, text figs. 75, 76, and Pl. XLII, figs. 17*a*, 17*b*.

Described from near the mouth of Judith River, this is one of the most characteristic of the fresh-water species found in the formation. It has been collected at many localities in the original area, and along Milk River above Havre, Mont. Whiteaves reports it also from the South Saskatchewan, Bow, and Belly rivers in Alberta.

GONIOBASIS JUDITHENSIS n. sp.

Pl. XIII, fig. 4.

Shell of moderate size, stout, consisting of seven or eight very convex whorls; aperture very slightly produced below; surface marked by narrow, sharply elevated revolving lines, of which four to six are visible on the spire, separated by broader, flat bands which bear numerous minute revolving striæ, and crossed by very fine growth lines.

Height of an average specimen, 22 mm.; breadth, 13 mm.

This species is probably the ancestor of *Goniobasis tenuicarinata* M. & H., from which it differs in being larger, with more robust form, and with more narrow, more evenly distributed, and somewhat less prominent revolving lines or ridges.

It is common in the fresh-water beds of the Judith River on Dog Creek and at other localities near Judith, Mont., on Cow Creek, and on Milk River from Havre to the Canadian boundary. The figured specimen is from Simpson's ranch, on Milk River about 10 miles south of the boundary.

RHYTOPHORUS ? GLABER Whiteaves.

Rhytophorus? glaber Whiteaves, 1885, Cont. Canadian Palæont., vol. 1, p. 69, Pl. X, figs. 4, 4*a*–4*c*.

This peculiar little species, originally reported from a number of widely distributed points in Alberta and Assiniboia, we collected only from the brackish layers near the base of the formation on Milk River in the neighborhood of Pendant d'Oreille, Assiniboia.

HELIX VETUSTA Meek and Hayden.

Helix vetusta Meek, 1876, Rept. U. S. Geol. Surv. Terr., vol. 9, p. 552, Pl. XLII, figs. 7*a*, 7*b*.

Mouth of Judith River.

HYALINA? EVANSI Meek and Hayden.

Hyalina? evansi Meek, 1876, Rept. U. S. Geol. Surv. Terr., vol. 9, p. 548, text figs. 68–70.

Mouth of Judith River; also in our collections from Cow Creek and at various points on Milk River from Havre to the Canadian boundary.

HYALINA? OCCIDENTALIS Meek and Hayden.

Hyalina? occidentalis Meek, 1876, Rept. U. S. Geol. Surv. Terr., vol. 9, p. 547, Pl. XLII, figs. 6*a*–6*d*.

Somewhat more common than the preceding species and with the same geographic distribution.

THAUMASTUS LIMNÆIFORMIS Meek and Hayden.

Thaumastus limnæiformis Meek, 1876, Rept. U. S. Geol. Surv. Terr., vol. 9, p. 553, Pl. XLIV, figs. 8*a*–8*d*.

Thaumastus limnæiformis Whiteaves, 1885, Cont. Canadian Palæont., vol. 1, p. 72.

Originally described from Laramie or Fort Union beds near the mouth of the Yellowstone, and, so far as known, does not occur in lower horizons in the United States. Whiteaves reports the species from both the Laramie and the Judith River in Canada.

VITRINA? OBLIQUA Meek and Hayden.

Vitrina? obliqua Meek, 1876, Rept. U. S. Geol. Surv. Terr., vol. 9, p. 545, Pl. XLII, figs. 10*a*, 10*b*.

Mouth of Judith River.

PLANORBIS (BATHYOMPHALUS) AMPLEXUS Meek and Hayden.

Planorbis (*Bathyomphalus*) *amplexus* Meek, 1876, Rept. U. S. Geol. Surv. Terr., vol. 9, p. 539, Pl. XLII, figs. 16*a*–16*c*.

Near mouth of Judith River. Represented in our collections from the same region and also from Cow Creek and on Milk River near Havre.

PLANORBIS PAUCIVOLVIS Whiteaves.

Planorbis paucivolvis Whiteaves, 1885, Cont. Canadian Palæont. vol. 1, p. 71, Pl. X, fig. 5.

From Judith River localities on Belly River and South Saskatchewan, Alberta.

PHYSA COPEI White.

Physa copei White, 1883, Third Ann. Rept. U. S. Geol. Survey, p. 450, Pl. XXV, figs. 1, 2.

Described from Judith River beds near Cow Island, Montana. The species is represented in our collections from Cow Creek, Dog Creek, and from several localities on Milk River from Havre to the Canadian boundary. Whiteaves reports it from many localities in both the Judith River and the Laramie of Alberta.

BULINUS SUBELONGATUS Meek and Hayden.

Bulinus subelongatus Meek, 1876, Rept. U. S. Geol. Surv. Terr., vol. 9, p. 540, Pl. XLII, figs. 13*a*, 13*b*.

Mouth of Judith River.

BULINUS ATAVUS White.

Bulinus atavus White, 1883, Third Ann. Rept. U. S. Geol. Survey, p. 450, Pl. XXV, figs. 6, 7.

Described from Dog Creek, Montana. Found also sparingly on Milk River near Havre.

CEPHALOPODA.

PLACENTICERAS sp.

Some fragments of a *Placenticeras* were seen in the marine stratum 150 feet below the top of the Judith River beds on Cow Creek 7 miles above its mouth. Like the other purely marine fossils found here, this ammonite does not really belong to the Judith River fauna, but as it occurs within the stratigraphic limits of the formation it is worthy of mention.

INSECTA.

Associated with the plants collected on Willow Creek 10 miles north of Musselshell post-office a single wing of an insect was found which has been identified by the entomologists of the United States National Museum as belonging to a cockroach.

GENERAL COMMENTS ON THE INVERTEBRATE FAUNA.

The species enumerated in the above list fall into the three general categories of marine, brackish-water, and fresh-water forms, the latter including a few more or less doubtful land shells.

As the Judith River is essentially a nonmarine formation, strictly speaking its fauna should not be made to include the species cited belonging to *Avicula*, *Crenella*, *Nucula*, *Leda*, *Tellina*, *Liopistha*, *Mactra*, *Lunatia*, and *Placenticeras*, which were brought into the Judith River area by a local, temporary invasion of pure marine waters. In our field studies we saw only one occurrence of this kind, and that was on Cow Creek, Montana, where, as already described, the evidence seems clear that the marine beds are on the same horizon and strictly contemporaneous with fresh- and brackish-water beds in the same neighborhood. There is no mixture of nonmarine with the marine invertebrates, but in an overlying stratum marine and land vertebrates are found commingled. The marine invertebrates found here belong to the faunas of the underlying and overlying formations.

The few marine fossils reported by Whiteaves from the Judith River beds in Canada may indicate a similar occurrence there, or possibly there has been an error in identifying the formation from which they came. With these exceptions no strictly marine fossils are known from the main mass of the Judith River beds, but at the base

and the top there is ample evidence of continuity with the underlying and overlying marine formations. In many cases the lithologic change is not exactly coincident with the faunal change, so that the topmost layers containing the Claggett fauna and the lowest beds containing the Bearpaw fauna often closely resemble the Judith River beds in lithologic features.

The brackish-water fauna has a wide geographic distribution, occurring in practically every area in which the Judith River formation is found, but it is confined to thin beds intercalated in the upper and lower portions of the formation. On Milk River near Pendant d'Oreille, southern Assiniboia, these layers with brackish-water shells are unusually well developed near the base of the formation, and there are several intercalated bands extending up about 100 feet above the base. The individual beds are usually not more than 1 or 2 feet in thickness and the intervening strata contain fresh-water invertebrates. Farther south, near Havre, and in the area along the Missouri, brackish-water bands are seldom found in the lower part of the formation, but in the upper 25 feet there is a very persistent oyster bed, varying in thickness from 1 to 4 feet, closely associated with a heavy bed of lignite. In some places there are two or three of these brackish-water beds close together near the top of the formation. According to the Canadian reports, an oyster bed occurs at about this horizon in many places in Alberta.

The following species are confined to the brackish-water layers:

Species confined to brackish-water layers of Judith River formation

Ostrea subtrigonalis.	Corbula perundata.
Ostrea glabra.	Panopæa simulatrix.
Mytilus sp.	Rhytophorus glaber.
Modiola sp.	Neritina sp.
Anomia gryphorhynchus.	Melania? whiteavesi.
Corbicula occidentalis.	Goniobasis convexa.
Corbicula cytheriformis.	Goniobasis convexa var. impressa.
Corbula subtrigonalis.	

The species of *Corbula*, *Corbicula*, and a few of the others apparently ranged into nearly fresh waters, as they are sometimes found associated in the same layer with abundant specimens of *Unio* and *Campeloma*, while the oyster beds represent more nearly marine conditions which did not permit the mingling of purely fresh-water forms. The three forms of gasteropods in this list, doubtfully referred to *Melania* and *Goniobasis*, occur in the oyster beds. It is noteworthy that the Laramie species, *Melania? wyomingensis* and *M.? insculpta*, also occur with brackish-water fossils, and the former has been found with marine associates in the upper layers of the Fox Hills.

By far the most abundant of the brackish-water forms is *Ostrea subtrigonalis*, which could probably furnish more individual specimens

than all the rest of the Judith River fauna together. Next to it in abundance are the species of *Corbula*, *Corbicula*, and *Anomia*, but their distribution is much more local and irregular. *Ostrea glabra* and a variety intermediate between it and *O. subtrigonalis* are locally abundant, but the differences between these oysters are chiefly in the size, and the relationship between the different forms seems to be analogous to that between the local and commercial varieties of *Ostrea virginica*.

The five forms of Gasteropoda enumerated in our brackish-water list all appear to be confined to the Judith River beds, and the brackish-water faunule as a whole has a distinctive facies that is not exactly duplicated elsewhere, and yet when the comparison is made species by species almost all the other forms are represented in the Laramie by similar if not identical species, and some of them are represented in other formations as low as the Colorado group. In fact, they are persistent types that range throughout the Upper Cretaceous, and forms similar to some of them exist in the present seas. It is obvious that such species can not be safely used singly in correlating over great distances, but within limited areas, when comparison is made with an entire assemblage of forms and checked by stratigraphic observations, their evidence is often to be depended upon, and is as convincing as any other paleontologic evidence. When full collections are compared it will usually be easy to distinguish between Judith River and Laramie from the brackish-water fossils alone, but if the collections are meager and fragmentary it may not be practicable to do so. This remark is based on experience with the two faunas in the United States. Comparing the oysters, in the Laramie the large *Ostrea glabra* is the common form, while in the Judith River *O. subtrigonalis* is by far the most abundant and most widely distributed. *Corbicula* also has a different development in the Laramie, the type represented by *C. occidentalis* and *C. cytheriformis* being comparatively rare, while there are many other species that are much more abundant. In Canada the lists of brackish-water fossils from the "Western Laramie," as given by Whiteaves, include practically all of the Judith River forms, and indicate that the two faunules are indistinguishable. On examining the descriptions of the localities at which these fossils were collected it is found that in the majority of cases the strata have steep dips or show other evidence of much disturbance, suggesting the possibility that the fossils in question may have really come from the Judith River instead of the Laramie. Another explanation, which is perhaps as reasonable, is that the Judith River brackish-water Mollusca really persisted in the far northwest to Laramie time as a continuous and practically unchanged faunule, while in the United States the break in continuity and resultant necessary migrations caused greater modification.

After removing from our list of species the few sporadic marine forms and those that are confined to the brackish-water bands in the upper and lower portions of the formation, there still remains a much larger number of fresh-water and land species of Mollusca. These characterize probably more than nine-tenths of the total thickness of the formation, though of course they are not uniformly distributed through it. Mention has already been made of the fact that *Unios* and other fresh-water shells are occasionally found in actual association with brackish-water species such as *Corbula*, *Neritina*, and *Corbicula*, but as a rule they are in distinct beds, even in the upper and lower parts of the formation, while the middle 300 or 400 feet contain none but fresh-water and land Mollusca, associated with vertebrates of similar habitat.

A considerable number of the fresh-water and land species are not found outside of the formation. A few apparently occur in the Laramie also, and others are represented in the Laramie by similar forms that are doubtless their direct descendants. Taken as a whole, the Judith River fauna is distinguished from that of the Laramie by the presence of many characteristic species that do not occur in the higher formation and by the absence of many of the most common and striking of the Laramie forms.

This difference is sufficiently conspicuous to have been recognized by all paleontologists who have studied the faunas, even when the formations were supposed to be nearly or quite contemporaneous.

In the systematic list, under the specific headings mention has been made of the fact that certain Judith River fresh-water species apparently recur in the Laramie and that others are represented there by forms so similar that they may be considered their direct descendants. We may cite as conspicuous examples of the first class *Unio danæ*, *U. priscus*, *U. cryptorhynchus*, and *Goniobasis gracilenta*, and of the second class *U. supenawensis*, *Sphærium planum*, *Campeloma vetula*, *Goniobasis judithensis*, and *Physa copei*. These, however, form a comparatively small proportion of the fauna, and there is a much larger list of forms that have not been recognized outside of the Judith River beds, and at least one form, *Goniobasis? subtortuosa*, conspicuous on account of its peculiar specific characters and wide distribution, has no near relative in the Laramie. On the other hand, there is an absence of many of the peculiar types of *Unio* and of such conspicuous forms as *Viviparus trochiformis* and *Tulotoma thompsoni*, common in the Laramie.

Taken as a whole, the fresh-water faunas of the Judith River and the Laramie are somewhat more distinct than the brackish-water faunas of the same formations, and with fairly complete collections it should not be difficult to distinguish them in the laboratory.

From the facts that have been stated concerning the distribution of the different kinds of invertebrates within the Judith River beds, we

may reach some conclusions as to the conditions under which the deposits were found, for these animals were inhabitants of the waters in which the sediments were laid down, and they give clear testimony concerning the character of the waters and their relations with the sea. It is evident that after the deposition of the Claggett formation a considerable area in north central Montana and in Alberta and Assiniboia emerged from the sea and became the habitat of land and fresh-water animals. Since there was no obvious break in the sedimentation, it is probable that the larger part of the area was covered by low-lying swamps and lagoons. For some time there were slight oscillations that occasionally for brief intervals brought large parts of the area down to sea level and gave the lagoons sufficient connection with the ocean to allow the growth of oysters and other brackish-water forms over areas that had been occupied by fresh waters. Then for a longer period, during which 300 or 400 feet of sediments were formed, there was no connection with marine waters, though it is not probable that the area was ever very many feet above tide. During this epoch the general upward movement was reversed, and when the subsidence progressed more rapidly than deposition connection with the sea was soon again established, bringing in, first, brackish waters with their oyster beds, over nearly the entire area, with probably local bays and straits having more open and direct oceanic connections, such as is indicated by the occurrence of marine fossils in the Judith River on Cow Creek. Finally marine conditions were fully established over the entire area, so far as known, and continued during the deposition of the Bearpaw shales.

PLATE XII.

PLATE XII.

Page.

Fig. 1. Unio priscus Meek and Hayden? 108

Figs. 2, 3, 4. Unio priscus var. abbreviatus n. var 108

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JUDITH RIVER MOLLUSCA.

PLATE XIII.

PLATE XIII.

Page.

Fig. 1. Unio subspatulatus Meek and Hayden 107
Figs. 2, 3. Unio supenawensis n. sp..... ... 109
Fig. 4. Goniobasis judithensis n. sp..... 117
Fig. 5. Melania whiteavesi n. sp..... 115

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JUDITH RIVER MOLLUSCA.

FOSSIL PLANTS OF THE JUDITH RIVER BEDS.

By F. H. KNOWLTON.

DESCRIPTIONS OF SPECIES.

FERNS.

Pl. XIV, fig. 1; Pl. XV, fig. 7.

Aside from the species below described as *Osmunda montanensis*, the collection contains minute fragments of two other evidently quite distinct ferns, upon which I have not ventured to bestow even generic names. The first of these, shown on Pl. XIV, fig. 1, is a fragment of what appears to be the extreme tip of a pinnule of an apparently very delicate fern. It is cut into several rounded lobes which are slightly decurrent along the stem or rachis. One of these, together with the terminal lobe, appears to have been toothed, but this is obscure. The frond seems to have been thick, and is apparently covered with minute papillæ. The nervation can not be made out satisfactorily. This fragment suggests the terminal portion of a pinnule of some of the lip ferns, *Cheilanthes*, but the material is not sufficient to warrant even generic determination, and it is only mentioned in the hope of calling attention to it in future.

On the same piece of matrix there are fragments of the terminal portions of several small pinnules, each being cut into several relatively strong lobes. The nervation is obscurely preserved, but appears to be only once forked. Its relationship is not apparent. It is shown on Pl. XV, fig. 7.

OSMUNDA MONTANENSIS n. sp.

Pl. XIV, fig. 6.

Shape of frond unknown; pinnule linear-lanceolate, obtusely wedge-shaped at base, rounded at apex; margin obscure, but apparently finely and sharply serrate; midrib strong, straight; nervation strong, arising at an acute angle, forking in an almost dichotomous manner three or exceptionally four times, the ultimate branches entering the sinuses between the marginal teeth.

Unfortunately this species is represented by a single pinnule only, which is linear or slightly linear-lanceolate in shape, with a very obtusely wedge-shaped base and a somewhat narrowed and rounded apex. The length is 22 mm. and the width about 7 mm. The margin is not very well preserved, but so far as can be made out it is finely and sharply serrate. The nervation as described above is well shown in the figure.

Among the few known living species this pinnule agrees most closely with those of *Osmunda regalis*, the well-known and widely spread Royal fern; in fact, the agreement is so close that with the limited material available it is impossible to note any essential difference in size, shape, marginal dentation, and nervation, the resemblance extending even to the ending of the ultimate nerve branches in the sinuses. But as we have no knowledge as to the shape of the whole frond, and, moreover, as the geologic horizon whence this comes is so remote from the present time, I have hesitated, even though the resemblance is so close, to regard it as a fossil representative of the living species. It is hardly to be presumed that a species could come down from the Cretaceous to the present without change. Additional material is much to be desired.

Some half a dozen fossil species of *Osmunda* have been described from North America, ranging in age from the Potomac to the Eocene. The Potomac species described by Fontaine[a] may be dismissed at once, as they do not suggest the present form in the least. The species approaching it most closely in size is *Osmunda öbergiana* Heer[b] from the lower Atanekerdluk beds of Greenland, but this differs in having entire margins and only once-forked nerves; in nervation ours is nearest to *O. doroschkiana* Göpp.[c] (the *O. torrelli* of Heer and Lesquereux), from the Miocene of Sachalin, but the size and margin are not in accord. *Osmundites skidegatensis* of Penhallow,[d] from the Lower Cretaceous of Skidegate Inlet, Queen Charlotte Islands, has the pinnules too fragmentary to admit of satisfactory comparison.

Locality.—Willow Creek, Fergus County, Mont., about 12 miles north of Musselshell post-office and 1 mile east of road from Junction City to Fort Maginnis.

CYPERACITES sp.

On several pieces of matrix there are fragments of narrow grass-like or sedge-like leaves that require at least to be mentioned, although they are not of sufficient size or well enough preserved to be of any value. The longest fragments are under 6 cm. in length and show a width of 3 or 4 mm., and are provided with numerous close, parallel

[a] Potomac flora: Mon. U. S. Geol. Survey, vol. 15, 1889, pp. 145–147.
[b] Fl. Foss. Arct., vol. 3, pt. 2, Pl. XXVI, figs. 9–9b.
[c] Op. cit., vol. 5, pt. 3, Pl. I, fig. 4.
[d] Trans. Roy. Soc. Canada, vol. 8, sec. 4, pp. 3–29.

veins. They have not been figured, as they are too characterless to be of value.

Locality.—Willow Creek, Fergus County, Mont., about 12 miles north of Musselshell post-office and 1 mile east of road from Junction City to Fort Maginnis.

SEQUOIA REICHENBACHI (Geinitz) Heer.

Pl. XIV, figs. 3–5.

This is by far the most abundant form in the collection, there being hundreds of specimens, while there is hardly a piece of matrix that does not show it in greater or less profusion. It is present from large branches nearly 2 cm. in thickness, from which nearly all the leaves have fallen, to great clusters of branchlets and even those just unfolding, and in one or two instances there are branchlets showing the male aments in a good state of preservation. I have selected for illustration a few to show the range of size and appearance.

Unfortunately this species is of little value in fixing age within narrow limits, as it is of almost world-wide distribution within the Cretaceous. In this country it occurs very abundantly in the Potomac, and has been reported in greater or less abundance and with greater or less degree of certainty in the Kootenai of Great Falls, Mont., the Dakota group at Fort Harker, Kans., the Belly River series at Belly River, Canada, the clay marl at Cliffwood, N. J., the Amboy clay at Woodbridge, N. J., the Montana formation at Point of Rocks, Wyoming, the Livingston beds in the Bozeman coal field of Montana, etc.

I have very carefully compared these specimens with the illustrations of *Sequoia reichenbachi* in all the literature available, and I am not able to separate them from this form. As would be expected from such a mass of material, there are differences in size and to some extent in appearance, but these are connected by all possible gradations and are undoubtedly to be explained on the ground of robust and perfect development and the completeness of the suite of specimens.

Locality.—Willow Creek, Fergus County, Mont., about 12 miles north of Musselshell post-office and 1 mile east of road from Junction City to Fort Maginnis.

SEQUOIA sp.? (cone).

Pl. XIV, fig. 2.

From the Judith River beds 10 miles northwest of Wild Horse Lake, Alberta, Mr. Stanton obtained a single, much-broken cone that appears to belong to *Sequoia*. It is globular in shape, being about 3 cm. long and nearly the same in width, but it is somewhat flattened and the exact dimensions can not be ascertained with certainty. The

scales were very large and thick, apparently not more than five showing in a vertical view. No attachment for the cone is observable.

This cone appears to be very similar, except as regards size, to *Sequoia heerii* Lesq.,[a] from the western Tertiary. This, however, does not exceed 1.5 cm. in long diameter, while the one in hand exceeds 3 cm., which is too great a difference for reasonable specific variation. This also suggests certain cones of *S. reichenbachi* as figured by Heer[b] from the Kome and Pattorfik beds of Greenland, but it is too much broken to be positive.

Locality.—Judith River beds 10 miles northwest of Wild Horse Lake, Assiniboia.

SEQUOIA HETEROPHYLLA? Velenovsky.

Pl. XVI, fig. 5.

Sequoia heterophylla Velenovsky, Gymnosp. d. Bohm. Kreidf., p. 22, Pl. XII, fig. 12; Pl. XIII, figs. 2–4, 6–9.

Among the hundreds of coniferous branches in this collection there is but a single one, together with its counterpart, that appears to belong to this species. It is a small piece, about 5 cm. in length, of the upper portion of a branchlet, and bears rather small, relatively broad and abruptly pointed leaves, which, in the lower part of the branchlet, are remote and approximately opposite. The leaves are slightly narrowed at the base and are decurrent for a considerable distance down the stem—in fact, reaching down to and apparently overlapped by the leaves next below. In the lower portion of the branchlet the leaves are open and spreading, but they become closer and more erect at the tip.

The marked characteristics of this species as defined by its author, and as interpreted by Newberry from the Amboy clays, is the heterophyllous form of the leaves, those at the base of the branchlets being shorter, smaller, and more appressed; while above, the leaves are more scattered and spreading, though ordinarily not to the extent shown in the lower portion of the Willow Creek specimens. This, however, compares very closely with figs. 2–4 of Velenovsky's Pl. XIII (op. cit.), as it does with Newberry's Pl. VI (op. cit.), figs. 3, 5, and 13. In the upper part of the branchlet, where the leaves become more erect, it is not possible to distinguish our specimen from the ordinary branchlets of *S. heterophyllus*. The lowest leaves preserved in the Willow Creek specimens are slightly smaller than those a little above, which is an indication that, had the whole branchlet been preserved, they would show a still further reduction. Thus I am convinced that the specimens in hand are correctly referred to the above species; yet, as there is but

[a] Tert. Flora: Rept. U. S. Geol. Surv. Terr., vol. 7, Pl. VII, fig. 13. Also Newberry, Later extinct floras of North America: Mon. U. S. Geol. Survey, vol. 35, 1898, Pl. XLVII, fig. 7.

[b] *Fl. Foss. Arct.*, vol. 3, pt. 2, Pl. XX, figs. 1, 2.

a single example, and this not a complete branchlet, I have hesitated to record the identification as absolutely certain.

Sequoia heterophylla was described by Velenovsky from the Upper Cretaceous (Cenomanian and Senonian) of Bohemia, and in this country has been found abundantly in the Amboy clays by Newberry and sparingly in the Upper Cretaceous of Staten Island (Kreischerville) by Hollick,[a] in the Tuscaloosa of Alabama by Smith,[b] and by Ward[c] in the so-called Lower and Upper Albirupean (Later Potomac) of Virginia. In some of the localities above enumerated, except in the Amboy clays, it is not present in numbers sufficient to remove all suspicion as to the correctness of the determination, although the material was perhaps as satisfactory in some cases as that now in hand.

Locality.—Willow Creek, Fergus County, Mont., about 12 miles north of Musselshell post-office and 1 mile east of road from Junction City to Fort Maginnis.

THUJA CRETACEA? (Heer) Newberry.

Pl. XVI, figs. 3, 3*a*.

Thuja cretacea (Heer) Newberry, Flora Amboy Clays, p. 53, Pl. X, figs. 1, 1*a*.
Libocedrus cretacea Heer, Fl. Foss. Arct., vol. 6, pt. 2, p. 49, Pl. XXIX, figs. 1, 2; Pl. XLIII, fig. 1*d*.

The collection contains four small pieces which I am unable to distinguish from *Thuja cretacea*. These specimens show very well the size and arrangement of the branchlets, but unfortunately they are not sufficiently well preserved to show clearly the shape of the leaves, though in one small area their outline can be faintly made out. I can see no difference in the size and disposition of the branchlets, nor for that matter in the leaves, between them and *Thuja cretacea*, yet as there is a slight doubt, I have questioned the specific determination.

Heer described his *Libocedrus cretacea* from the Ataneschichten of Greenland, and apparently the same form was identified by Newberry from the Amboy clays of South Amboy, N. J. The latter author changed the generic name to *Thuja* on what seems good grounds.

These specimens have some resemblance to *Thuja interrupta* Newb.,[d] from the Fort Union beds near the mouth of the Yellowstone, but are distinguished at once by their more slender, graceful habit, and by not being enlarged at the extremity of the branchlets.

Locality.—Willow Creek, Fergus County, Mont., about 12 miles north of Musselshell post-office and 1 mile east of road from Junction City to Fort Maginnis.

[a] Trans. New York Acad. Sci., vol. 12, p. 30, Pl. I, fig. 21.
[b] Geol. Surv. Alabama, 1894, p. 348.
[c] Potomac formation: Fifteenth Ann. Rept. U. S. Geol. Survey, p. 378 et seq.
[d] Later extinct floras of North America: Mon. U. S. Geol. Survey, vol. 35, Pl. XXVI, figs. 5–5*d*.

DAMMARA ACICULARIS n. sp.

Pl. XV, figs. 2–5.

Cone scales broad and very thick at apex, narrowed below into a broad, thick basal portion; apex broadly rounded, provided in the center with a long, slender, acute, apparently depressed awn; body of scale with several (8 to 10) strong apparently concentric ribs, which are pressed close together and pass down the narrowed basal portion as thin striæ.

The collection contains a large number of these scales, evidently from a large cone, all of them detached and most of them widely separated, though occasionally several of them are found near together or even overlapping. The smallest one observed has a width of 11 mm. at the distal end, while the broadest one noted is 16 or 17 mm.; the majority of them are 14 or 15 mm. broad. The slender, awl-shaped awn shows an extreme length of 5 mm., but the usual length is 3 or 4 mm.; it appears to have been directed downward in the perfect cone. The length of the scales is about 18 mm., exclusive of the awn, and the width of the narrowed basal portion 3 or 4 mm.

This species shows unmistakable affinity with forms described by Heer from the Ataneschichten and Patootschichten of Greenland, but may be distinguished from them at once by the long, sharp awn. In size it is perhaps nearest to *Dammara microlepis* Heer,[a] which shows a width of 14 mm., but it is described by its author as having an obtuse, rounded apex and an attenuated base. In shape and the disposition of the ribs or striæ it is more like *D. borealis* Heer,[b] but this is 22 mm. broad and has a shorter, thicker basal portion.

Both the Greenland species are without the awn so characteristic of the specimens under consideration, though *D. borealis* is stated by Heer to have the apex apiculate. Doctor Newberry identified[c] this latter species in the Amboy clays, where he states it to be abundant, but the only specimen he figures is as small as, or even smaller than, the smallest one observed from Willow Creek. The figure shows a short apiculate apex and is not unlike some of ours from which the awn has been broken, but as he has "found numbers of them sometimes associated together, often scattered," and makes no mention of the presence of an awn, it was probably not a character of the Amboy clay form. What is probably the same species, though mentioned under the name of *Eucalyptus geinitzi* Heer,[d] was found by Mr. David White in the Cretaceous of Marthas Vineyard, but the figured specimen shows no evidence of the awn, nor is it mentioned, although Mr. White states that this species is one of the commonest forms present

[a] Fl. Foss. Arct. vol. 6, pt. 2, p. 55, Pl. XL, fig. 5.
[b] Op. cit., p. 54, Pl. XXVII, fig. 5.
[c] Flora Amboy clays: Mon. U. S. Geol. Survey, vol. 26, p. 47, Pl. X, fig. 8.
[d] Am. Jour. Sci., 3d ser., vol. 39, 1890, p. 98, Pl. II, fig. 10.

at that place. The reasons for regarding Heer's *Eucalyptus geinitzi* as at least generically similar to Dammara are well set forth by Newberry in his monograph on the Amboy clay flora (p. 47).

The same form, or at least a form very closely allied to it, is described and figured by Velenovsky [a] from the Upper Cretaceous of Bohemia, also under the name of *Eucalyptus geinitzi*, and it is also reported from the Cenomanian of Moravia. It would seem that these must all belong to one genus, and that a conifer.

Locality.—Willow Creek, Fergus County, Mont., about 12 miles north of Musselshell post-office, and 1 mile east of road from Junction City to Fort Maginnis.

CUNNINGHAMITES ELEGANS (Corda) Endlicher.

Pl. XV, fig. 1.

Cunhinghamites elegans (Corda) Endlicher, Synop. Conif., p. 270.
Cunninghamia elegans (Corda) in Reuss, Verstein. Bohm. Kreidef., pt. 2, p. 93, Pl. XLIX, figs. 29–31.

The collection contains portions of three or four thick branches, rather closely beset with long narrow leaves that I think must be referred without doubt to this species. The longest and best of these, shown on Pl. XV, fig. 1, is about 15 cm. in length and shows a thickness of 1 cm. While the leaves are not very well preserved, they are at least 3 cm. long and 3 mm. or more in width, and the scars left on the branch by their fall are 5 mm. or more long and about 3 mm. broad; they are apparently 1-nerved.

The specimen here figured, together with another smaller one, is not to be distinguished from figures of this species given by Newberry [b] from the upper part of the Amboy clay at Keyport, N. J. It is of about the same size, and has the same large leaves and scars.

Cunninghamites elegans, first described from Moletein in Moravia and from Mseno in Bohemia, was also found by Heer [c] in the Patoot beds of Greenland, and according to him the forms from the lower Senonian of Westphalia referred by Hosius and von der Marck [d] to *Cunninghamites squamosus* should belong here also.

Locality.—Willow Creek, Fergus County, Mont., about 12 miles north of Musselshell post-office and 1 mile east of road from Junction City to Fort Maginnis.

[a] Foss. Fl. böhm. Kreidef., vol. 4, Pl. II (XXV), figs. 8–11.
[b] Flora Amboy clays: Mon. U. S. Geol. Survey, vol. 26, p. 48, Pl. V, fig. 1.
[c] Fl. Foss. Arct., vol. 7, Pl. LIII, fig. 1*a*.
[d] Fl. d. Westf. Kreidef.: Palæontogr., vol. 26, Pl. XXXVII.

CUNNINGHAMITES RECURVATUS? Hosius and von der Marck.

Pl. XVI, fig. 6.

Cunninghamites recurvatus Hosius and von der Marck, Fl. d. Westf. Kreidef.: Palæontogr., vol. 26, p. 179 (55), Pl. XXXVII, figs. 143, 144.

Associated with the last is the specimen here figured, which seems to belong to this species. It is a fragment from the middle of a branch; is between 8 and 9 cm. in length, and 3 or 4 mm. in thickness. The leaves are not very well preserved, but they are over 2 cm. in length, and, so far as can be made out, about 2 mm. in width at or near the base, and taper from near the middle to a narrow, acute point. They arise at a low angle and are somewhat decurved. The scars left on the branch by their fall can not be determined, as the specimen is too poorly preserved at this point.

In view of the fact that this species is not only found in the same beds with the last-mentioned species, but has a fragment of it on the same piece of matrix, it is entirely possible that this example is incorrectly determined. It may possibly be a smaller branchlet of *C. elegans* with the leaves slightly recurved, but it agrees almost perfectly with the figures given of *C. recurvatus*, and I have referred it provisionally to this species. The type locality of *C. recurvatus* is the *Scaphites binodosus* zone of the lower Senonian of Westphalia.

Locality.—Willow Creek, Fungus County, Mont , about 12 miles north of Musselshell post-office and 1 mile east of road from Junction City to Fort Maginnis.

CUNNINGHAMITES PULCHELLUS n. sp.

Pl. XVI, fig. 1.

Branches apparently slender, leaves alternate, somewhat remote, broad and thick at base, turning abruptly at right angles to the stem, very long, narrow, sharp-pointed at apex, thick in texture and apparently deeply channeled above; leaf-bases large, oblong, obtusely acute, keeled and provided in the lower part with several fine striæ.

This form is represented by several very well-preserved branches, the best of which is here figured. The greatest thickness observed in a branch is 6 or 7 mm., and the least about 3 mm. Lateral branches slender, arising at intervals of some 2 or 3 cm., alternate and nearly at right angles to the main branch. Leaves persistent for at least two seasons, disposed spirally, with enlarged bases closely appressed to the branch, just above which they turn abruptly at right angles and are then straight or sometimes slightly depressed. Length of the leaves from 2 to 3 cm., and their width 2 mm. or less. As stated above, the leaves appear very narrow and stiff, their upper surface apparently being deeply channeled.

The specimen shown in Pl. XVI, fig. 1, evidently represents portions of two seasons' growth, the lower segment, showing the origin

of three lateral spurs, being clothed with shorter, more slender leaves, which are closer together, while the upper portion shows a period of more active growth, in which the leaves are slightly more scattered and larger and decidedly longer than those below. In all cases, however, the leaves just above their thickened base turn abruptly at right angles to the branch. By taking an impression of the branch with modeling clay or wax the original shape of the branch is approximately restored and the size and shape of the leaf bases become clear. It appears that the leaves are distributed on all sides of the branch in a regular spiral manner, a fact which is also shown in a fortunate fracture across the branch, showing the leaves going down into the matrix on what is now the underside of the stem. The thickened and ribbed base of a leaf is closely appressed to the branch, being overlapped at base by the leaves below and itself in turn partially overlapping the one next above. While there is no positive evidence to show how the leaves separated from the branch, it is probable that they were cut off at or near the point where the right-angled turn of the blade is made, which would leave behind the thick base. But, as already pointed out, it is certain that the leaves were persistent for some time, probably several seasons.

This fossil form has been very carefully compared with the only living species of *Cunninghamia* (*C. sinensis*) of China and Japan, and the points of agreement are so many as to leave no doubt regarding their generic identity. In the living species the leaves are distributed in a spiral manner and have the same thickened bases, which overlap and are in turn overlapped by others, as in the fossil. By taking an impression in clay of a branch of about the same size as some of the fossil branches, a mold is obtained which agrees in essential particulars with the fossil impression. By the strong curving of the leaves on the lower side of a branch they are made to assume a flat, more or less two-ranked disposition, and it is quite possible that a similar condition may have existed in the fossil. The leaves are evidently persistent for several years, as there is no evidence in any of the specimens available for study of a disposition to fall. The leaves in the living species, while of about the same size and shape as in the fossil, differ in having finely serrate margins and several faint parallel ribs, instead of what appears to be a channel in the middle.

So far as I have been able to find, the nearest approach among fossil forms to the one under consideration is the one which was called *Abietites setigera* by Lesquereux,[a] but which has been later regarded as merely rootlets, a view I have myself held; but since seeing the material from Willow Creek I am decidedly of the opinion that Lesquereux's specimens actually represent a conifer. It seems quite impossible, however, that they could belong to *Abietites* on the ground of analogy

[a] Ter. Flora: Rept. U. S. Geol. Surv. Terr., vol. 7, p. 82, Pl. VII, figs. 17, 18.

with the living *Abies* or *Picea*, since in both these the leaves fall with the greatest ease. In discussing his *Abietites setigera*, Lesquereux states that he had submitted it to Saporta, who informed him that he had an undoubtedly identical form from the Upper Cretaceous of St. Paulet, Gard, France. Saporta disagreed with Lesquereux as to the affinity of the fossil in question, but the latter does not mention what Saporta proposed to call it, nor have I thus far been able to find any mention of such a plant in Saporta's works, or of an account of the plants of St. Paulet.

Among species of *Cunninghamites* the one in hand appears to approach most closely to *C. recurvatus* Hos. and v. d. Marck,[a] from the Lower Senonian of Westphalia; in other words, to the preceding species. In that species the leaves, while somewhat recurved, arise at a considerable angle, whereas in this the leaves are at a decided right angle. This difference is really not great, yet the appearance of the two is very different, but it is possible that with a larger series of specimens of the former this apparent distinction might disappear. I have hesitated to think that there could be three well-marked species of so rare a genus in the same beds, yet this is by no means without precedent.

Locality.—Willow Creek, Fergus County, Mont., about 12 miles north of Musselshell post-office and 1 mile east of road from Junction City to Fort Maginnis.

POPULUS CRETACEA n. sp.

Pl. XVII, figs. 1–5.

Leaves coriaceous in texture, ovate or elliptical-ovate in shape, very obtusely wedge-shaped, sometimes almost truncate, at base; rather obtuse or somewhat rounded at apex; margin entire at base, becoming coarsely undulate-toothed above, the teeth usually very much rounded, sometimes more nearly acute, occasionally with a small tooth between the larger ones; petiole slender, not fully preserved; midrib strong, passing straight to the apex; secondaries strong, 4 or 5 pairs, alternate, remote, lower pair arising at or a little above the top of the petiole, with several (3 or 4) branches on the outer or lower side, some of which pass directly to the margin, while others unite into broad loops and send small branches to the teeth; upper secondaries straight, or more frequently curved upward, often forked, the branches passing to the teeth, or, especially in the upper part of the blade, with the secondaries uniting by broad bow well inside the margin and sending slender branches into the teeth; nervilles rather obscure, apparently irregular and mainly percurrent; finer nervation obscure.

This species, if I am correct in supposing that all here included actually belong to one form, is a very polymorphous one and

[a] *Fl. d. westf. Kreidef.*: Palæontogr. vol. 26, p. 179, Pl. XXXVII, figs. 143, 144.

shows considerable variation in size, shape, marginal teeth, and nervation, and yet with the ample material in hand it seems impossible to draw any satisfactory line between them. What is assumed to be the typical form is shown in Pl. XVII, fig. 1. It is elliptical-ovate in general outline, with an abruptly and very obtusely wedge-shaped base and rather few, low, mostly rounded teeth, and has the lower pair of secondaries arising above the top of the petiole; its length is 6.5 cm. and its width about 4 cm. Agreeing with this in size and in the marginal teeth, but with a more nearly truncate base and the lower secondaries arising at the extreme base of the blade, is the form shown in fig. 5. Its length can not be ascertained, but the width is the same as that of the form first described. Of a smaller size and a more nearly elliptical outline is the leaf shown in fig. 3, in which the teeth are relatively larger and the lower secondaries apparently take their origin above the base of the blade. Its length is 4 cm. and its width 3 cm., and a little more than 1 cm. of the petiole is preserved. The smallest leaf regarded as belonging here is that shown in fig. 16*d*. It is only 2.5 cm. in length and a little over 2 cm. in width. The extreme in another direction is exhibited in fig. 2, which is more nearly ovate in outline and has an abruptly rounded base with a small deltoid extension down the petiole. Its marginal teeth are obscure, but so far as can made out the margin is merely undulate in the lower portion, but becomes regularly toothed in the upper part. The lowest pair of secondaries arise some distance above the base of the blade. The length of this example is about 6.5 cm. and the width 5.5 cm. It is possible that this last may not belong with the others, but I have several specimens which seem to connect it with them, and it may at least provisionally be regarded as the same.

I have been much puzzled as to the correct generic reference of these leaves, and had at first supposed that they belonged to *Quercus*, but a somewhat extended search among living and fossil forms has not disclosed anything that can be regarded as especially close. Thus at first sight they seem to suggest certain of the forms of *Quercus westfalica* Hos. and v. d. Marck,[a] from the Upper Senonian of Westphalia, but in these the secondaries are much more numerous and in no case do the lower pairs arise at the top of the petiole, nor are they branched on the lower side as in the Willow Creek leaves. I have finally concluded, on the ground of their obvious and close resemblance to the leaves of the living *Populus grandidentata* Michx., that they are best referred to *Populus*. In looking through the specimens of the living species in the National Herbarium it is easy to select examples from many parts of the country in which the resemblance is really striking.

[a] Fl. d. Westf. Kreidef.: Palæontogr, vol. 26, Pl. XXIX and XXX.

They have the same ovate shape, with the rounded or obtusely wedge-shape base, and while the teeth vary somewhat in character, in many cases they are low and rounded, as in the fossil. The apex of the leaf is always pointed, but is more or less rounded in the fossil. The lowest pair of secondaries always arise at the very base of the blade, whereas in the fossil they may or may not do so. The other nervation is also quite like that in the Willow Creek specimens, but it is more inclined to be camptodrome, though not infrequently the secondaries enter the teeth directly.

Locality.—Willow Creek, Fergus County, Mont., about 12 miles north of Musselshell post-office and 1 mile east of road from Junction City to Fort Maginnis.

POPULUS sp.

Pl. XIX, fig. 1.

The collection contains a single fragment that appears to belong to *Populus*, but it is, unfortunately, not well preserved. It is a small leaf, apparently almost circular in shape, being about 3 cm. broad and possibly a little less in length. The margin is uncertain, but appears to be undulate. The petiole is very long and slender, over 2.5 cm. of it being preserved. The nervation consists of 5 ribs arising from the top of the petiole, the three middle ones being strong and once forked, the branches often uniting before reaching the margin, while the lateral ones on each side are slenderer and apparently unbranched. At the base of each of these outside ribs is a small secondary branch which has much the appearance of another rib. The nervilles, so far as can be made out, seem to be irregularly reticulated.

In size, shape, and the long petiole this fragment suggests *Populus rotundifolia* Newb.,[a] from the Fort Union beds of Montana, but the nervation, as well as can be determined, appears different, and the margin can not be compared. In size and shape, also, it is like *P. flabellum* Newb.,[b] from the supposed Upper Cretaceous of Puget Sound, but the nervation is quite different. The status can not be fixed until more and better material is forthcoming.

Lacality.—Willow Creek, Fergus County, Mont., about 12 miles north of Musselshell post-office and 1 mile east of road from Junction City to Fort Maginnis.

POPULITES AMPLUS n. sp.

Pl. XVIII, fig. 1.

Leaf coriaceous in texture, apparently very broadly ovate in shape; base destroyed, but apparently truncate; apex very obtuse and

[a] Later extinct floras of North America: Mon. U. S. Geol. Survey, vol. 35, Pl. XXIX, figs. 1–4.
[b] Op. cit., Pl. XX, fig. 4,

rounded; margin with apparently one large, obtuse, lateral lobe, but others provided with obscure, faint, remote teeth; midrib of moderate strength, somewhat zigzag in the upper portion; secondaries four pairs, craspedodrome, the lowest pair straight, apparently opposite, and arising at or near the top of the petiole, provided with several branches on the lower side; upper secondaries remote, alternate, much arched upward, usually with two or three strong forks, all branches entering the margin in very slight marginal dentations; nervilles few, strong, and irregular.

The example figured is the only one contained in the collection, and unfortunately this is imperfect in that it lacks the basal portion. It is a large leaf of thick texture, and so far as can be made out is very broadly and obtusely ovate in outline, with a single rather large lobe on one side and faint indications of scattered marginal teeth. The length is about 9 cm. and the width nearly the same; possibly the length may have been a little more when the leaf was in perfect shape. From the appearance of the larger, lower pair of secondaries it would seem that they were opposite and at or near the top of the petiole, giving rise to an obscurely 3-nerved condition.

This form seems to find its closest relationship with the genus *Populites*, as described by Lesquereux, from the Dakota group. For instance, it suggests in a general way *P. letigiosus* (Heer) Lesq.,[a] being of approximately the same shape and with the same type of nervation, but it differs specifically in its much larger size and fewer, more arched, secondaries. In shape and disposition of the nerves it also suggests *Populus? cordifolia* Newb.,[b] from the Dakota at Blackbird Hill, Nebraska, which is figured as having a serrate margin.

Locality.—Willow Creek, Fergus County, Mont., about 12 miles north of Musselshell post-office and 1 mile east of road from Junction City to Fort Maginnis.

BETULITES? HATCHERI n. sp.

Pl. XVIII, fig. 3.

Leaf small, apparently of firm texture, approximately circular in outline, slightly heart-shaped at base, rounded at apex; margin rather coarsely toothed, the teeth broad and obtuse (petiole not preserved); midrib strong, irregular or zigzag; secondaries, about five pairs, strong, especially the basal ones, which arise at a nearly right angle, the others being at an angle of 30° or 40°; lower pair of secondaries with four or five slender tertiary branches on the lower side, which unite in a broad bow some distance inside the margin; upper secondaries forked at about two-thirds the distance between the midrib and

[a] Flora Dakota group: Mon. U. S. Geol. Survey, vol. 17, Pl. VII, fig. 7; Pl. VIII, fig. 5, etc.
[b] Later extinct floras of North America: Mon. U. S. Geol. Survey, vol. 35, Pl. III, fig. 7.

margin, the branches uniting and sending slender slips from the outside of the bows to the marginal teeth; nervilles numerous, very strong, mostly unbroken and at right angles to the secondaries.

This is another form represented by a single specimen, but it is well characterized by its small size, nearly circular or very broadly ovate outline, coarsely toothed margin, and peculiar strong nervation. The length is 2.5 cm. and the width about 3 cm. It is well shown in the figure.

I am uncertain as to the proper generic reference for this little leaf. Although differing greatly in size, the shape and general character of the nervation are strongly suggestive of certain species of *Viburnites* from the Dakota group of Kansas. Thus *V. crassus* Lesq.[a] has a heart-shaped base and coarse-toothed margin as well as a strong nervation, but the teeth are lower and more acute and the secondaries after forking do not unite so distinctly, but pass directly to the margin. A similar criticism applies to *Viburnites masoni* Lesq.,[b] though with less force. Certain of Lesquereux's species of *Protophyllum*, which, by the way, are hardly to be separated from some forms of *Viburnites*, agree very well in shape, but have a more or less peltate base and distinctly forking secondaries, while in *Populites* the margin is somewhat different and the secondary nervation is strongly forked. Altogether this leaf seems to approach more closely to some of the forms of the highly polymorphous *Betulites westii* Lesq.,[c] of the Dakota group. In size and shape it agrees very well with *B. westii subintegrifolius*, and in shape, size, and marginal teeth with *B. westii reniformis*. But in these forms, as well as in all but one of the other varieties, the secondaries usually fork and pass to the margin without uniting. In *B. westii grewiopsideus*,[d] however, the upper secondaries unite in exactly the same manner as in the leaf under consideration, and it is consequently referred to the same genus, although with a mark of interrogation. I do not think this leaf is sufficiently close to any of the forms of *Betulites westii* to warrant placing it with them, but, as above indicated, it does not seem generically distinct from them. In any event it is a well-marked leaf and can easily be identified if found in future.

Locality.—Willow Creek, Fergus County, Mont., about 12 miles north of Musselshell post-office and 1 mile east of road from Junction City to Fort Maginnis.

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[a] Flora Dakota group: Mon. U. S. Geol. Survey, vol. 17, Pl. XLV, figs. 1-4.
[b] Op. cit., Pl. XLV, fig. 5.
[c] Op. cit., Pls. IV and V.
[d] Op. cit., Pl. LXIV, fig. 10.

QUERCUS MONTANA n. sp.

Pl. XVII, fig. 6.

Leaf of firm texture, ovate in shape, with a very obtusely wedge-shaped base and an obtuse apex; margin perfectly entire below along the wedge-shaped portion of the base, regularly and coarsely undulate-toothed above, the teeth obtuse and rounded; petiole slender, of moderate length; midrib of moderate strength, straight; secondaries, four or five pairs, rather slender, alternate or subopposite, remote, passing directly to marginal teeth or forking and the branches entering the teeth; nervilles numerous, mostly unbroken.

The example figured is all that can with certainty be referred to this form. It is ovate in shape, with a peculiarly straight and obtusely wedge-shaped base and coarse-toothed margin. The length is about 6 cm. and the width about 5 cm., while the petiole, which seems to be entirely preserved, has a length of a little more than 1 cm. The nervation is well shown in the figure.

I am uncertain as to the generic reference of this leaf, and it may possibly be an extremely aberrant form of what has been described as *Populus cretacea* (p. 138), but I do not think so. It has the peculiar base described above, very regularly toothed margins, and the lowest pair of secondaries arising at a distance above the top of the petiole, although at the extreme base of the blade is a pair of very thin secondary branches, which only proceed for a short distance.

Among fossil forms this seems to find its greatest affinity with *Quercus suspecta* Lesq.,[a] from the Dakota group of Ellsworth County, Kans. The latter, however, is broader, being elliptical rather than ovate, more obtuse at apex, and has more numerous secondaries, which all seem to enter the larger marginal teeth. The finer nervation is not preserved in the Kansas leaf mentioned.

Lesquereux regards his species as being most closely related to *Q. wilmsii* Hos., and *Q. latissima* Hos.,[b] from the Upper Cretaceous of Westphalia, but neither one seems to approach very closely to the form in hand.

Locality.—Willow Creek, Fergus County, Mont., about 12 miles north of Musselshell post-office and 1 mile east of road from Junction City to Fort Maginnis.

QUERCUS JUDITHÆ n. sp.

Pl. XVIII, fig. 2.

Leaf rather membranaceous in texture; apparently obovate in shape, truncate at base, and broadly rounded at apex; margin undulate-toothed, the teeth largest near the middle and becoming more shal-

[a] Flora Dakota group: Mon. U. S. Geol. Survey, vol. 17, Pl. XLVII, fig. 7.
[b] Dicotyl. Westf. Kreidef.: Palæontogr., vol. 17, Pls. XII and XIII.

lowly undulate at the apex; midrib rather slender, zigzag, especially above; secondaries slender, five or six pairs, alternate, remote, forking, and sometimes ending in the marginal teeth, but usually joining the one above and sending thinner branches to the margin; finer nervation obscure, but apparently forming irregular meshes.

The specimen figured is all that was found in the collection, and unfortunately this is quite imperfect, lacking most of the sides below. As nearly as can be made out it was obovate in outline, being about 9 cm. in length and about 7 cm. in width. It seems to be allied to the preceding species and even to that described as *Populus cretacea*, but its obovate outline and somewhat different nervation are perhaps sufficient to characterize it.

Locality.—Willow Creek, Fergus County, Mont., about 12 miles north of Musselshell post-office and 1 mile east of road from Junction City to Fort Maginnis.

SAPINDUS INEXPECTANS n. sp.?

Pl. XVII, fig. 7

Leaf small, membranaceous in texture, elliptical-ovate in shape, apparently rounded at base, obtuse at apex; midrib slender, straight; secondaries stout, about six pairs, subopposite, at an angle of about 45°, much curved upward, camptodrome, each joining the one next above; nervilles numerous, thin, mainly broken, and forming large, irregular areas.

This little leaf, the only one contained in the collection, is elliptical-ovate in outline, about 3.5 cm. in length and 2.25 cm. in width. The nervation is shown in the drawing.

I have not attempted much search for the close relatives of this species, as the single specimen available is of such a nondescript character that it would be difficult to work out satisfactorily its relationship.

Locality.—Willow Creek, Fergus County, Mont., about 12 miles north of Musselshell post-office and 1 mile east of road from Junction City to Fort Maginnis.

TRAPA? MICROPHYLLA Lesquereux.

From the base of the Judith River beds, at a point on Cow Creek about 13 miles above its mouth, Mr. Stanton has obtained about fifteen specimens of small detached leaves or leaflets that I am not able to distinguish from this species. While they are all smaller than the usual examples from the type locality (Point of Rocks, Wyoming), they agree well in shape and the marginal dentation, but unfortunately have not retained the nervation, or at most but slight traces of it. This species, or, at least, what has been so identified, has been figured by Dawson, in Tyrrell's collections from Bad Lands, Red Deer, and

Rosebud rivers, and Pincher Creek, Canada, the age of which he regards as "Lower Laramie," and also a single doubtful example "from the Upper Laramie of Great Valley."[a]

Professor Ward found this species abundantly at Burns ranch, on lower Yellowstone River, Montana, in beds supposed to be of Fort Union age; but, as I have shown in the Flora of the Montana Formation (p. 63 et seq.), I can not believe that these should be referred to *T. microphylla*, for the reason that they are clearly compound leaves, rarely detached, whereas at the type locality and at all the points mentioned by Dawson they are always separated and show no evidence of having been compound. I found examples that are not to be distinguished, apparently, from the Burns ranch forms, on Wolverine Creek, in the Yellowstone National Park, in beds regarded as of true Laramie age,[b] and in 1896 Mr. Stanton and myself found a large number of detached leaves in Converse County, Wyo., in clay beds in the lower portion of the true Laramie.[c] It may be that my presumption of two forms being mixed under this name is not valid, but it is certainly remarkable that at two localities they should always give evidence of being compound and at all the other localities appear as detached leaves, with no indication of being compound, especially as the material is ample in most cases. It must be confessed, however, that when dealing with isolated leaves or leaflets it is impossible to draw any satisfactory line between them.

Locality.—Cow Creek, Montana, 13 miles above its mouth.

TRAPA? CUNEATA Knowlton.

Trapa? cuneata Knowlton, Flora Montana formation: Bull. U. S. Geol. Survey No. 163, 1900, p. 64, Pl. V, fig. 6.

The Willow Creek material contains a single, somewhat imperfect example, which is practically indistinguishable from my *T. cuneata* from Point of Rocks, Wyoming. It has the same obovate-cuneate outline, being broad and obtuse above and wedge-shaped below, and shows the same obtuse teeth confined to the upper third of the blade. It is slightly larger, being about 2.5 cm. long and a little over 1.5 cm. wide, while the Point of Rocks species is 2 cm. long and slightly over 1 cm. wide. The only point of difference is a very slight one in the midrib, this in the type specimen being "slender, somewhat flexuous, with several very slender, flexuous, often forking, branches," and in the one under discussion it is even less pronounced; in fact, hardly to be made out at all. But this character is perhaps not of much importance when considered in relation to the condition prevailing in *Trapa? microphylla* Lesq., of which a great many speci-

[a] Cf. Trans. Roy. Soc. Canada, vol. 4, p. 31 (1886).
[b] Mon. U. S. Geol. Survey, vol. 32, pt. 2, p. 661, Pl. LXXVII, figs. 3, 4.
[c] Flora Montana formation: Bull. U. S. Geol. Survey No. 163, p. 63.

mens have been found, and in which the midrib is sometimes quite distinct and at others very faint or almost obsolete. The general nervation, however, is identical in the two specimens, and it seems safe to regard the Willow Creek example as the same as *T. cuneata*. It is not necessary to go into the question of the generic reference of these curious little leaves, as this has been done several times before.[a]

Locality.—Willow Creek, Fergus County, Mont., about 12 miles north of Musselshell post-office and 1 mile east of road from Junction City to Fort Maginnis.

DIOSPYROS JUDITHÆ n. sp.

Pl. XVIII, figs. 4, 5; Pl. XIX, fig. 3.

Leaves membranaceous in texture, elliptical-lanceolate in shape, broadest at or near the middle, from which they narrow about equally to the acute base and acuminate apex; margin entire; petiole short; midrib of medium strength for the size of the blade, straight; secondaries five or six pairs, thin, alternate, irregular, camptodrome, arching well inside the margin and joining the one next above; lower secondaries very thin and forming a series of bows just inside the margin; nervilles numerous, very thin, mainly percurrent, and approximately at right angles to the secondaries.

This form is represented by about half a dozen examples, which show such a range in size as to suggest the possibility of two species being confused, but there seems no other line except that of size to be drawn between them. They all have the elliptical-lanceolate outline and are all about equally narrowed to both base and apex. The largest, shown in Pl. XVIII, fig. 5, is about 6 cm. long and 3.5 cm. wide; it is quite imperfect, lacking the apex and most of one side. The next in size, shown in fig. 3, is 4.5 cm. long and 2.25 cm. wide; its petiole, seemingly entire, is 4 mm. in length. In fig. 4 is shown the smallest leaf, this being 3 cm. long and about 14 mm. wide.

These leaves are referred to the genus *Diospyros* from their agreement with certain leaves from the Dakota group of Kansas so referred by Lesquereux. For example, it is similar to some of the leaves referred to *D. kansaseana* Lesq.,[b] but more particularly with *D. primæva* Heer,[c] which was originally from the Dakota group of Nebraska, but also since found in Kansas. In both of these species, however, the secondaries are more numerous than in the Willow Creek specimens, and the petiole and midrib are much stronger.

It was at first supposed that these leaves should belong to the Celastraceæ on account of their resemblance to certain forms of *Celastrus*,

[a] Cf. Flora Montana formation: Bull. U. S. Geol. Survey No. 163, pp. 62–64.
[b] Flora Dakota group: Mon. U. S. Geol. Survey, vol. 17, Pl. XVII, figs. 1, 2, etc.
[c] Op. cit., Pl. XX, figs. 1, 2.

Euonymus, etc., but the resemblance is perhaps closer with *Diospyros*, as above pointed out.

Locality.—Willow Creek, Fergus County, Mont., about 12 miles north of Musselshell post-office and 1 mile east of road from Junction City to Fort Maginnis.

CASTALIA STANTONI n. sp.

Pl. XIX, fig. 4.

Leaf large, evidently thick and of firm texture, approximately circular in outline; deeply cordate at base, the sinus rather broad and the lower lobes rounded; apex very obtuse and rounded; margins very faintly and obscurely toothed; petiole evidently thick and strong; nervation pinnate, the midrib relatively thin, straight; secondaries, five or six pairs, strong, subopposite, arising at an angle of about 45°, lowest secondaries with several (four or five) branches on the lower side, which fork two or three times and supply the lateral lobes, the branches passing to the minute marginal teeth; upper secondaries with one to three, occasionally uniting forks, the ultimate branches entering the marginal teeth; nervilles numerous, strong, mainly broken.

This splendid leaf, which is preserved practically entire, is the only one of its kind in the collection. It is nearly circular, the length from the top of the petiole to the apex being about 11 cm., and the width at the broadest point a little more than 12 cm.; the lateral lobes extend downward below the top of the petiole for a distance of about 2.5 cm. While the central or midrib is not particularly strong, the remainder of the nervation is abundantly so for the size of the leaf.

There seems to be little or no doubt as to the propriety of referring this leaf to the genus *Castalia*, since, for example, it agrees very closely in size and shape with many leaves of *C. odorata* of eastern North America or *C. alba* of the Old World. It has, however, a shallower, broader basal sinus than is usual in most leaves of these species, and the lobes are more obtuse and rounded, yet in this respect it is not greatly unlike other species, such, for instance, as what has been called *C. elegans* (Hook.) from Guatemala. In most species of *Castalia* the margin is perfectly entire, yet there are notable exceptions, as in *C. ampla* (Salsb.) of Mexico and the West Indies, *C. lotus* and *C. thermalis* of the Old World, and *C. gigantea* (Hook.) of Australia. In the fossil form under consideration the margin is very slightly but unmistakably toothed. As regards nervation, in most living species of *Castalia* the secondaries after forking are more or less united, thus inclosing a large and one or two series of smaller areas, while in some—e. g. *C. ampla*—the secondaries are practically united from near the midrib into numerous series of large aerolæ. In

the splendid *C. gigantea* of Australia, however, the secondaries are little or not at all joined, but fork several times and send the ultimate branches to the margin. Thus, as regards marginal dentation and nervation, our fossil leaf seems to agree most closely with the Australian species mentioned.

The only other species of the genus thus far detected in this country is the doubtful *Castalia? duttoniana* Knowlton[a] from the Montana formation at Dutton Creek, Laramie Plains, Wyo. This latter form, however, is a very different leaf, being hardly half the size of the one before us, broadly elliptical, very slightly heart-shaped at base and entire-margined; the nervation is also different, and it may not be correctly referred to *Castalia*.

Locality.—Willow Creek, Fergus County, Mont., about 12 miles north of Musselshell post-office and 1 mile east of road from Junction City to Fort Maginnis.

PHYLLITES DENTICULATUS n. sp.

Pl. XIX, fig. 2.

Leaf of small size and very thick texture; shape ovate, being apparently rounded at base and obtusely pointed at apex; margin entire at base, becoming strongly toothed above, the teeth being slender, sharp-pointed, and upward or outward turning; midrib rather slender, apparently zigzag; secondaries, three or four pairs, alternate, arising at a low angle and much curving upward, craspedodrome, entering the teeth, or forked and the branches entering the marginal teeth; finer nervation not observable.

This little leaf, the only one of its kind found in the collection, is evidently of thick texture, as the nervation can be made out with difficulty. It lacks both base and apex, but as nearly as can be determined its length was about 2 cm. and the width 1.5 cm.

I am uncertain as to the generic relations of this leaf, and moreover the single example is hardly well enough preserved to warrant speculation on this point.

Locality.—Willow Creek, Fergus County, Mont., about 12 miles north of Musselshell post-office and 1 mile east of road from Junction City to Fort Maginnis.

PHYLLITES INTRICATA n. sp.

Pl. XVIII, fig. 6.

The collection contains also another fragmentary example of a small leaf of doubtful affinity. It appears to have been rather membranaceous in texture, regularly ovate in shape with an apparently truncate or slightly cordate base and an acute apex. The margin is provided

[a] *Flora* Montana formation: Bull. U. S. Geol. Survey No. 163, p. 55, Pl. XIII, fig. 7.

with a few relatively large, coarse teeth. The nervation is very thin, consisting of a slender, straight midrib, and two or three pairs of very thin secondaries which arise at an acute angle and are greatly curved upward, ending apparently in or just below the sinuses. The length of this little leaf was 2 cm. and the width about 1.25 cm.

This leaf suggests in a way certain herbaceous plants, but I am wholly at a loss as to its probable affinities, and simply present it in the hope that more material may subsequently be secured.

Locality.—Willow Creek, Fergus County, Mont., about 12 miles north of Musselshell post-office and 1 mile east of road from Junction City to Fort Maginnis.

CARPITES JUDITHÆ n. sp

Pl. XVI, fig. 4.

Fruit evidently of firm texture, possibly a stone fruit; broadly obovate in shape, with a rather broad point of attachment and a regularly and obtusely rounded apex; fruit marked with numerous fine striæ which arise at the apparent base, at which point they are slightly stronger, and after spreading slightly in the middle converge toward the apparent apex.

The fruit here figured is all of its kind in the collection. It is perfectly preserved. It is rounded obovate, 14 mm. long and 11 mm. broad. It is provided with numerous fine striæ which converge at what is assumed to be the apex. The smaller end is presumed to be the point at which it was attached, as the striæ or ribs are thicker at this place. Its affinity is unrecognized.

Locality.—Willow Creek, Fergus County, Mont., about 12 miles north of Musselshell post-office and 1 mile east of road from Junction City to Fort Maginnis.

CARPITES PRUNI n. sp.

Pl. XV, fig. 6, 6*a*.

Fruit apparently of shelly or bony texture, broadly and obtusely ovate in shape, basal part rounded and apparently truncate; apex obtusely rounded; body of fruit marked with a marginal rib or thickened rim, and two or three longitudinal ribs.

This fruit is also the only one of its form contained in the collection. It is broad or elliptical-ovate in shape, with a very broad base and an obtuse apex. The length is 13 mm. and the width 11 mm. It suggests in a remote way the stone of a *Prunus*, but its affinity is a matter of question.

Locality.—Willow Creek, Fergus County, Mont., about 12 miles north of Musselshell post-office and 1 mile east of road from Junction City to Fort Maginnis.

CARPITES ALATUS n. sp.

Pl. XVI, fig. 2.

The collection contains two specimens of a very peculiar winged fruit that I am unable to determine satisfactorily. The best example, shown in Pl. XVI, fig. 2, is two-winged, the wings being broad and rounded, and separated by a deep, rounded sinus. The portion containing the nucleus extends as a long point, wingless (?) at the apex, but with the wings apparently arising below the apex and extending backward. The length over all is about 12 mm. and the greatest width about the same, the nuclear portion from the rounded sinus between the wings to its apex has a length of 6 mm., and the greatest width of the individual wings about 5 mm. In another example, which is presumed to be the same species, there is shown just one-half of the fruit, with the sharp-pointed nuclear portion and large rounded backward-extending wing. The dimensions are about the same as in the other. Neither shows any apparent point of attachment.

The other specimen, which has not been figured, is not unlike a single-winged coniferous fruit, such as *Pinus*, *Abies*, etc., while the figured one suggests the same, except that there is no evidence of a line of division between them, as should be the case if it is a double fruit. There seems to be only one nucleus or seed provided with a double wing in this specimen, but if the other example really belongs with it, it is probable that the division line is too obscure to be made out.

It is to be presumed that these are the fruits of a cone-bearing tree, possibly *Pinus* or something not greatly different, but in view of the anomalous features presented it is deemed best, as the material is so scanty, to present it here under the name of *Carpites* and wait for future material to settle the question.

Locality.—Willow Creek, Fergus County, Mont., about 12 miles north of Musselshell post-office and 1 mile east of road from Junction City to Fort Maginnis.

DISCUSSION OF THE FLORA.

In 1900, when I published my paper entitled "Flora of the Montana Formation," I took occasion to describe a small collection of fossil plants from a point on the right bank of Missouri River about 7 miles below the Coal Banks, just below the Great Bend of the Missouri. The beds whence these plants came were at the time supposed to be of Belly River age, as they appeared to be essentially in the position occupied by beds so called by the Canadian geologists, beyond the international boundary.

After setting forth briefly the then current though somewhat conflicting opinions regarding the areal extent and stratigraphic position

of the Belly River beds, I offered as an excuse for including the plants in the Montana flora the contention of some writers, notably Dr. C. A. White, that these beds were synchronous in part at least with the Montana formation, instead of being wholly below it, as held by others. Subsequent events have proved that it was correct to include them in the Montana flora, though not within the Belly River beds as at present understood.

At the time my bulletin was in press Mr. W. H. Weed had in course of publication his Benton folio,[a] in which he separated the plant-bearing beds in the vicinity of the Coal Banks under the name of the Eagle formation. He placed it between the Colorado and Montana groups, as separating them, but the subsequent investigations of Messrs. Hatcher and Stanton,[b] as already set forth in this bulletin, make it the lowest member of the Montana group, and separated by the Claggett formation from the Judith River beds, which are now regarded as the complete equivalent of the Belly River beds.

The beds below the Coal Banks have afforded the following forms of plants:[c]

Thinnfeldia montana Knowlton.
Quercus? montanensis Knowlton.
Ficus missouriensis Knowlton.
Juglans? missouriensis Knowlton.
Laurus? sp.
Liriodendron alatum Newberry MSS. Hollick.
Platanus? wardii Knowlton.

As these plants were supposed at that time to belong to the Belly River beds, I assembled for purposes of comparison a list of all the known forms that have been found in beds regarded as of this age in the Canadian Belly River. The result was disappointing, for not one of the Coal Banks species was found to be identical with or to have special affinity with the Canadian Belly River, but on the other hand they did show an unmistakable affinity with the Dakota group, and two species (*Thinnfeldia montana* and *Liriodendron alatum*) were regarded as belonging to the true Laramie. The species of *Liriodendron*, with which the Coal Banks form seems identical, was described originally from very rich plant deposits at Florence, Colo., and while this material has not yet been worked up, I am of the opinion that it may prove to be older than the true Laramie, and on this point Doctor Hollick now agrees with me.

The other species (*Thinnfeldia montana*) I was not able to separate from examples found in the Laramie of the Bozeman coal field.

As regards the affinity of the Coal Banks leaves with Dakota group forms, I probably underestimate rather than overestimate it; in fact, I should incline to regard what I then called *Platanus? wardii* as a

[a] Geologic Atlas of United States, folio 55.
[b] Cf. Science, Aug. 14, 1903, Vol. XVIII, pp. 211, 212.
[c] Flora Montana Formation, pp. 11-15, Pls. I, II.

species of *Populites*, possibly the same as Lesquereux's *P. elegans*[a] from the Dakota group at Fort Harker, Kans.; and further, it would not have done great violence to the facts had I identified my *Ficus missouriensis* with *Ficus glascœana* Lesq., and *Laurus* sp. with *Laurus knowltoni* Lesq., both from the Dakota of Kansas. There are slight differences, however, as I pointed out at the time, and it is perhaps best to regard them as distinct, at least until further material can be obtained.

So far as it seems possible to ascertain at the present time, it is more than likely that the Eagle formation will be found to be identical with the Dunvegan group of Dr. G. M. Dawson,[b] for the stratigraphic position, lithologic character, and fossil plants are similar.

From the Dunvegan group Sir William Dawson described[c] 19 species of plants, of which number six or seven were regarded as identical with Dakota group species, and a number of others were quite close to forms well known in the Dakota. Although none of the species from the Dunvegan group are regarded as actually identical with those of the Eagle formation, there are several that are not distantly related.

Since the delimitation of the Eagle formation, which carried with it the only fossil flora supposed to belong to the Belly River beds south of the international boundary, there have been no known plant-bearing beds of this age in the United States. The fortunate discovery by Messrs. Hatcher and Stanton of rich plant deposits in the Judith River beds on Willow Creek, Fergus County, Mont., about 12 miles north of Musselshell post-office and 1 mile east of the road from Junction City to Fort Maginnis, has now furnished a flora of at least 28 forms, as follows:

Fossil plants found in Judith River formation.

Fern, indeterminable.
Fern, indeterminable.
Osmunda montanensis n. sp.
Cyperacites? sp.
Sequoia reichenbachi (Gein.) Heer.
Sequoia heterophylla? Vel.
Sequoia sp.?
Thuja cretacea? (Heer) Newb.
Dammara acicularis n. sp.
Cunninghamites elegans (Corda) Endl.
Cunninghamites recurvatus Hos. and v. d. M
Cunninghamites pulchellus n. sp.
Populus cretacea n. sp.
Populus sp.
Populites amplus n. sp.
Betulites? hatcheri n. sp.
Quercus montana n. sp.
Quercus judithæ n. sp.
Sapindus inexpectans n. sp.
Trapa? microphylla Lesq.
Trapa? cuneata Knowlton.
Diospyros judithæ n. sp.
Castalia stantoni n. sp.
Phyllites denticulatus n. sp.
Phyllites intricata n. sp.
Carpites judithæ n. sp.
Carpites pruni n. sp.
Carpites alatus n. sp.

[a] Flora Dakota Group, Pl. XLVII, fig. 3.
[b] Geol. Surv. Canada, Rept. of Progress, 1879–80 (1881), p. 115B.
[c] Trans. Roy. Soc. Canada, Vol. I, Sec. IV, pp. 20–23.

In order that this flora may be compared with that from the beds north of the international boundary, it will be desirable to first present a complete list of the latter as left by Sir William Dawson. The fol lowing enumeration is from Bulletin No. 163 (p. 15) and is believed to be complete:

Fossil plants found in Canada.

Pistia corrugata Lesq. (leaves).
Pinus or Abies, type of Pityoxylon (Wood).
Sequoia, type of S. gigantea (Wood).
Sequoia, type of S. sempervirens (Wood).
Sequoia reichenbachi (Gein) Heer (leaves and branches).
Thuja, type of T. occidentalis (Wood).
Taxites, type of Taxus baccata (Wood).
Ginkgo, type of G. biloba (Wood).
Ginkgo? (fruit).
Lemna scutata Dawson (leaves).
Populus acerifolia Newb.? (leaf).
Populus latidentata Dawson (leaves).
Populus sp. (Wood).
Betula sp. (Wood).
Ulmus sp. (Wood).
Carya sp. (Wood).
Nelumbo dawsoni Hollick (Brasenia antiqua Dawson) (leaves).
Trapa cf. T. borealis Heer (fruit).
Platanus nobilis Newb.
Platanus? sp. (Wood).
Acer saskatchewense Dawson (leaf).

Much of this material is in the form of wood that has never been completely studied and is consequently of little value in an attempt to fix the age. If all of the remaining forms were correctly determined it would show the presence of a very remarkable association of species, but, as I have before suggested, it is more than likely that more than one horizon is represented. A reexamination of the evidence offered by Dawson leads me to place even less confidence in the determinations, since it shows how meager and uncertain much of the evidence was. Thus, of the presence of *Platanus nobilis* in the same beds (near Medicine Hat) with *Nelumbo dawsoni*, *Pistia corrugata*, *Lemna scutata*, *Trapa*, etc., he says:[a] "There are also fragments of the great leaves of *Platanus nobilis* and the *Populus* and *Acer* described below." So far as I can find, this is the only mention of material referred to this species, yet in subsequent mention it takes its place in lists and elsewhere with unquestioned value. So also with *Populus acerifolia* Newb., the only mention of which is under his *P. latidentata*,[b] where he states that "in the same matrix with the above are fragments of leaves of another *Populus*, of the type of *P. acerifolia* Newberry." Both of these species are typically Fort Union, and have never, so far as I know, been authentically identified in older beds, and I am consequently of the opinion that the present evidence is not sufficient to warrant regarding them as species of the Belly River or Judith River beds.

After dropping *Platanus nobilis* and *Populus acerifolia*, as seems warranted, we have left but three duly authenticated species in the Canadian Belly River beds that enjoy an outside distribution, viz:

[a] Trans. Roy. Soc. Canada, Vol. III, Sec. IV, p. 16, 1885.
[b] Op. cit., p. 16.

Pistia corrugata, which occurs in the Montana at Point of Rocks, Wyoming; *Sequoia reichenbachi*, which occurs widely throughout the Cretaceous of nearly all parts of the world, and *Lemna scutata*, which was described originally from the "Lignite Tertiary" near the forty-ninth parallel, and subsequently detected by Professor Ward in the Fort Union at Burns ranch, Montana, and by Dawson in the Laramie at Wood Mountain and Pincher Creek, British Columbia. Lesquereux reported it from Point of Rocks, Wyoming, but, as I have shown in Bulletin No. 163,[a] one of the examples he so identified is a small leaf of *Pistia corrugata* and the other a *Nelumbo* (*N. intermedia* Knowlton).

As to the affinities of the other named species, it may be mentioned that *Nelumbo dawsoni* is very closely allied to my *N. intermedia* from Point of Rocks, Wyoming, while the other two species (*Populus latidentata* and *Acer saskatchewense*) are not figured, nor are they described with sufficient fullness to permit of satisfactory comparison with other forms.

Turning now to the species described in this paper, mainly from Willow Creek, Montana, the reader will observe that the most striking feature of the list is the preponderance of conifers shown, since 8 of the 28 forms, or nearly one-third, belong to this group, and when the actual number of individual specimens is considered it is safe to say that fully nine-tenths belong to these species; and it may be added that the only species common to the Willow Creek locality and the Judith River beds north of the international boundary is *Sequoia reichenbachi*. This species, as already pointed out, is exceedingly abundant at the Montana locality, and Dawson speaks[b] of it as being abundant also at Medicine Hat in the Canadian beds of this age. It is possible that if the dicotyledons described by Dawson were illustrated they would show affinity with some of those I have described from Willow Creek, but this can not be determined now.

Of the 28 forms enumerated in this paper the following species enjoy an outside dispersal:

Sequoia reichenbachi.
Sequoia heterophylla?
Thuja cretacea?
Cunninghamites recurvatus.
Cunninghamites elegans.
Trapa? microphylla.
Trapa? cuneata.

As already mentioned, the first species (*Sequoia reichenbachi*) is very widely dispersed throughout the Cretaceous, occurring more or less abundantly in this country from the Potomac to the Livingston beds. *Sequoia heterophylla*, described originally from the Cenomanian and Senonian of Bohemia, has been found abundantly in the Amboy clays and sparingly at a number of other Upper Cretaceous localities. *Thuja cretacea* was first known from the Ataneschichten of Greenland,

[a] Flora Montana formation, p. 31.
[b] Trans. Roy. Soc. Canada, Vol. III, Sec. IV, p. 17 (under *Salisburia*).

and has been found by Newberry in the Amboy clays, while *Cunninghamites elegans* occurs in the upper part of the Amboy clays, in the Patoot beds of Greenland, and in the Upper Cretaceous of Moravia, Bohemia, and Westphalia. Of the two species of *Trapa*, *T. cuneata* is known only from, and *T. microphylla* originally from, the Montana at Point of Rocks, Wyoming. As set forth under *T. microphylla* (p. 145), it has been found also in the true Laramie and in the Fort Union.

Of the species that I have described as new, *Dammara acicularis* is perhaps nearest to *D. microlepis* Heer, from the Atane and Patoot beds of Greenland, and also under the name of *Eucalyptus geinitzi* from the Cenomanian of Moravia and the Upper Cretaceous of Bohemia and Marthas Vineyard. *Cunninghamites pulchellus* seems to be nearest to *C. recurvatus*, the distribution of which has already been given. The affinities of *Populus cretacea* are uncertain, but are perhaps closest with certain forms of *Quercus* described by Hoseus and von d. Marck from the Upper Senonian of Westphalia, while *Populus* sp. is very suggestive of forms of this genus, such as *P. rotundifolia*, from the Fort Union beds. The single large leaf that I have described as *Populites amplus* is quite closely related to certain species of this genus from the Dakota group, and *Betulites hatcheri* is close to *B. westii reniformis* Lesq., and *Quercus montana* approaches *Q. suspecta* Lesq., both from the Dakota. *Sapindus inexpectans*, based on a single small leaflet, has no very definite relationship, while the species of *Phyllites* and *Carpites* are in much the same state. *Diospyros judithæ* is very suggestive of *D. kansaseana* Lesq., or more particularly *D. primæva* Heer, from the Dakota of Kansas and Nebraska, while the large leaf described as *Castalia stantoni* is quite unlike anything thus far obtained in this country.

From this review it appears that the flora of the Judith River beds that has thus far come to light shows very little affinity with the true Laramie or the Fort Union, but does exhibit an undoubted relationship with that of the Dakota group or with the Cenomanian and Senonian of the Old World, or, in broad terms, with the lower and middle portions of the Upper Cretaceous.

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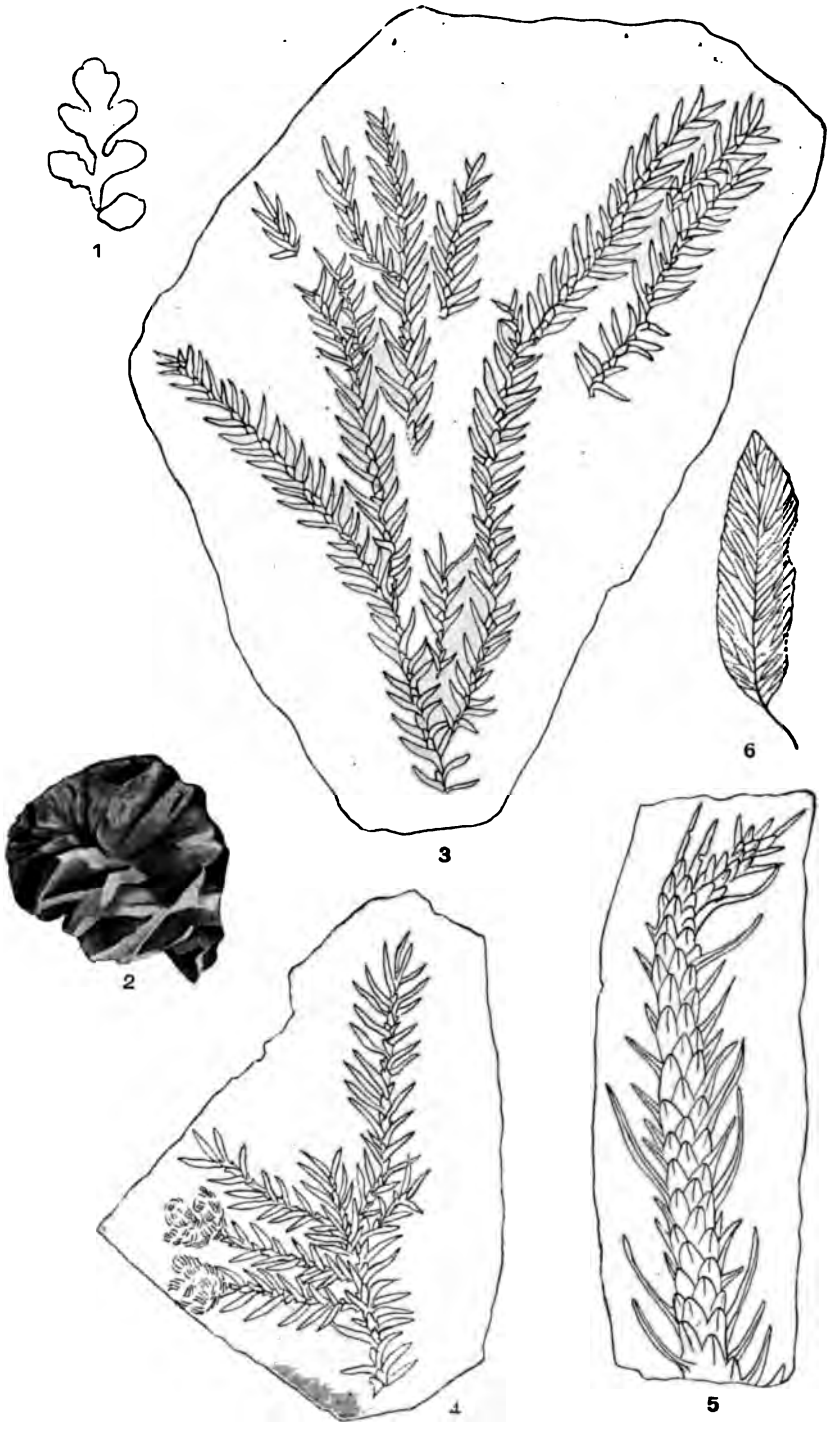

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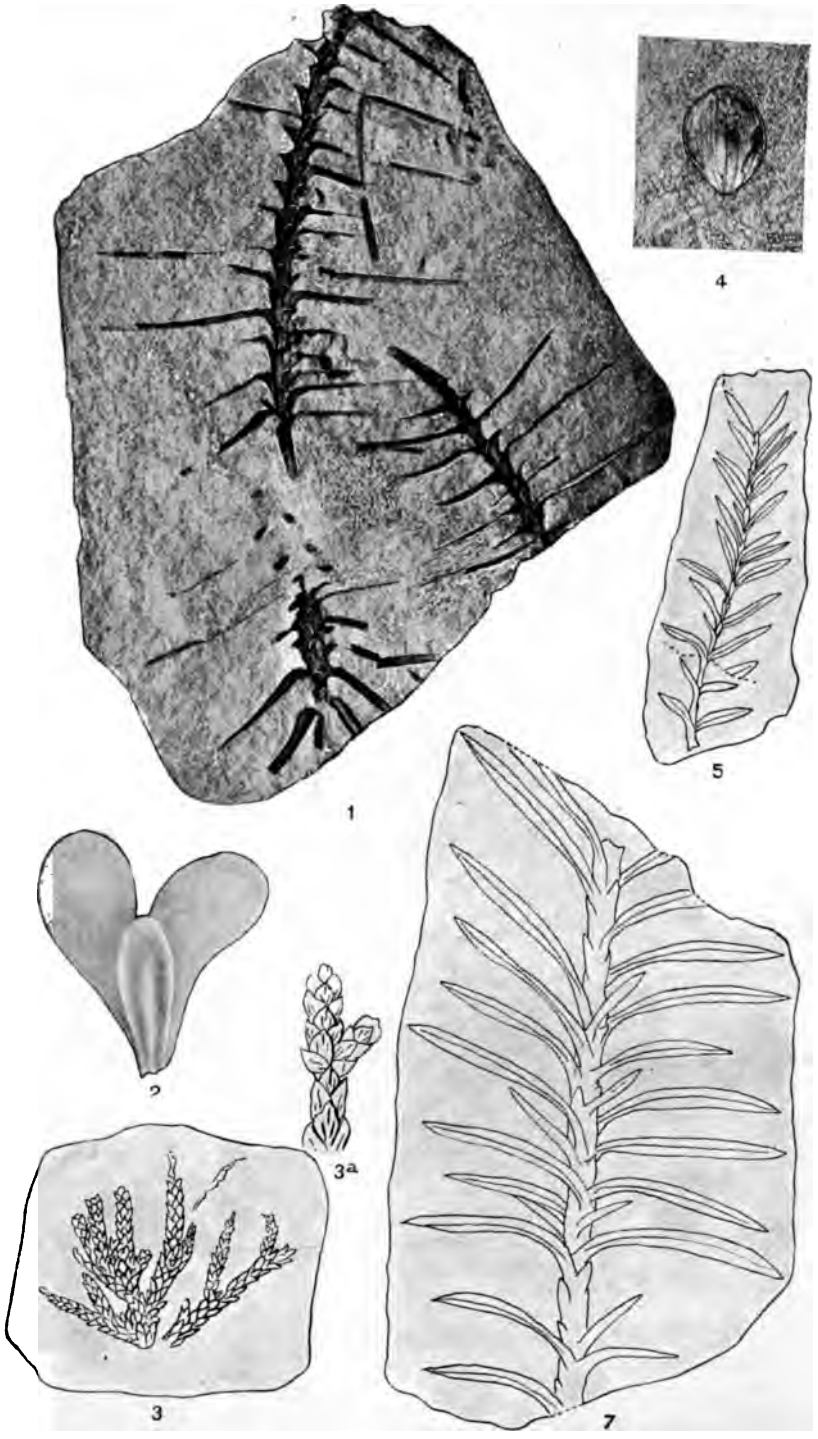

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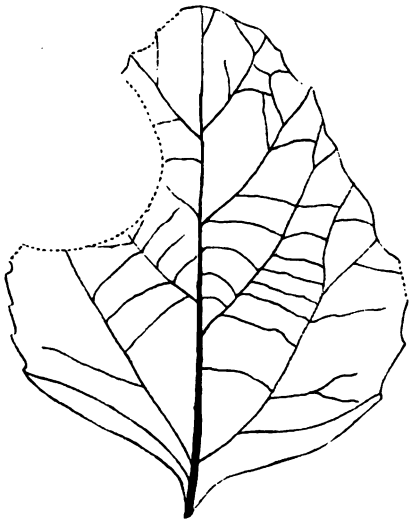

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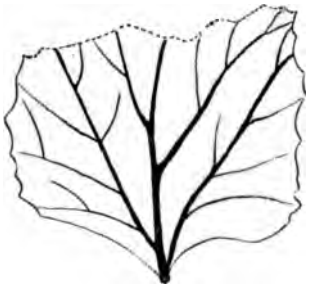

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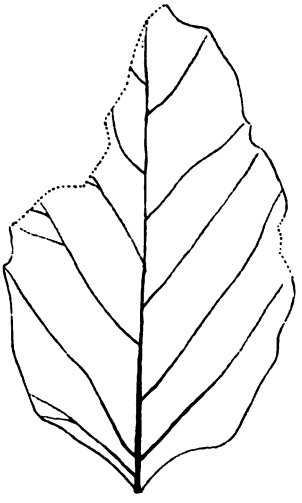

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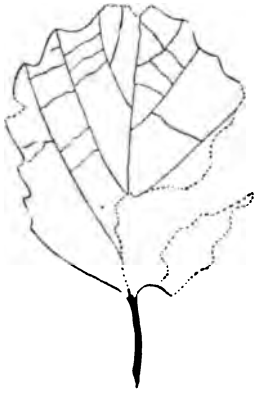

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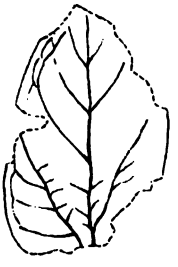

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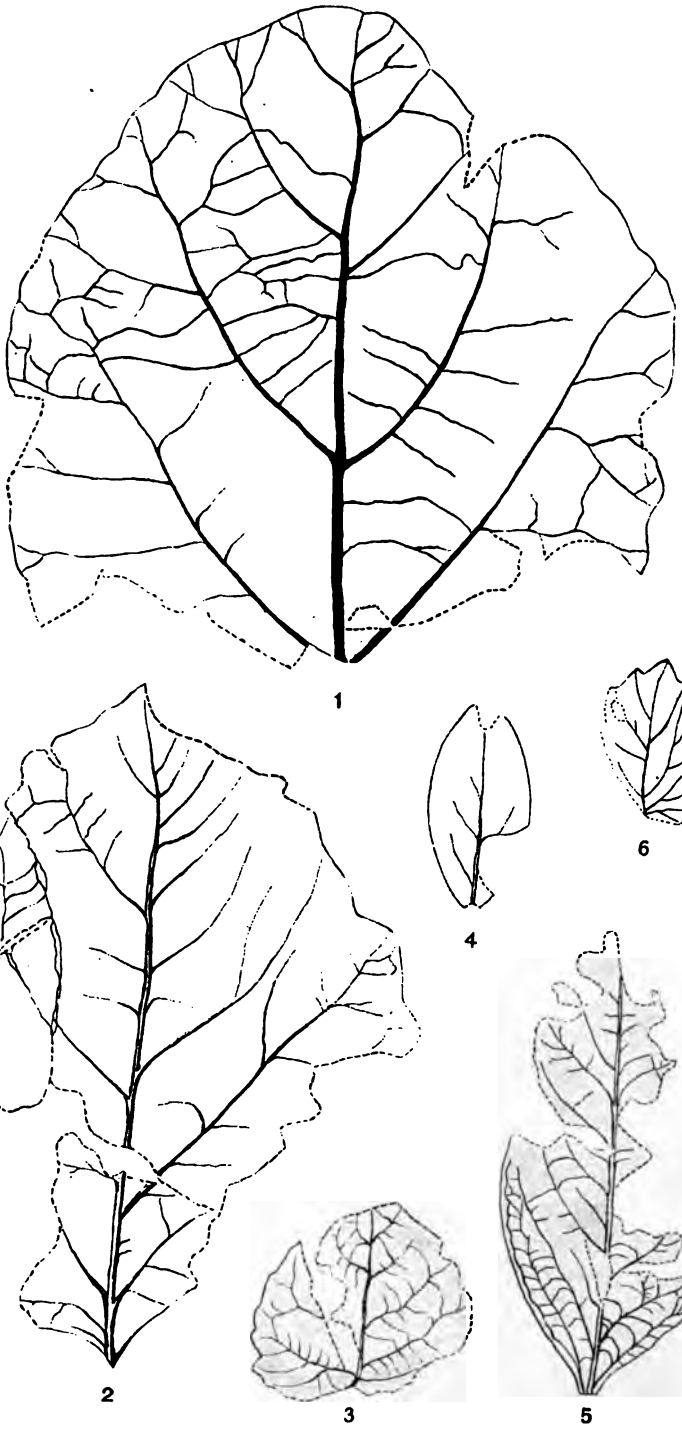

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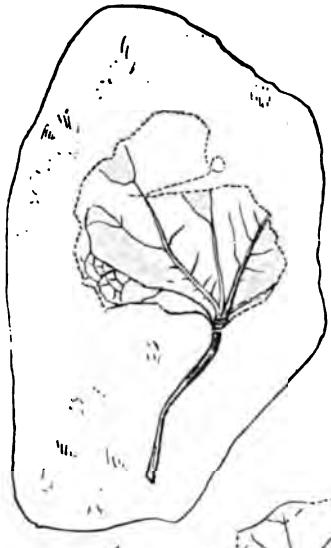

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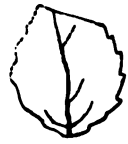

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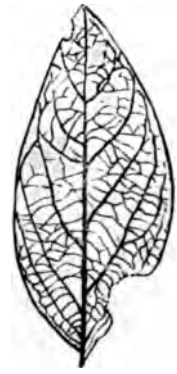

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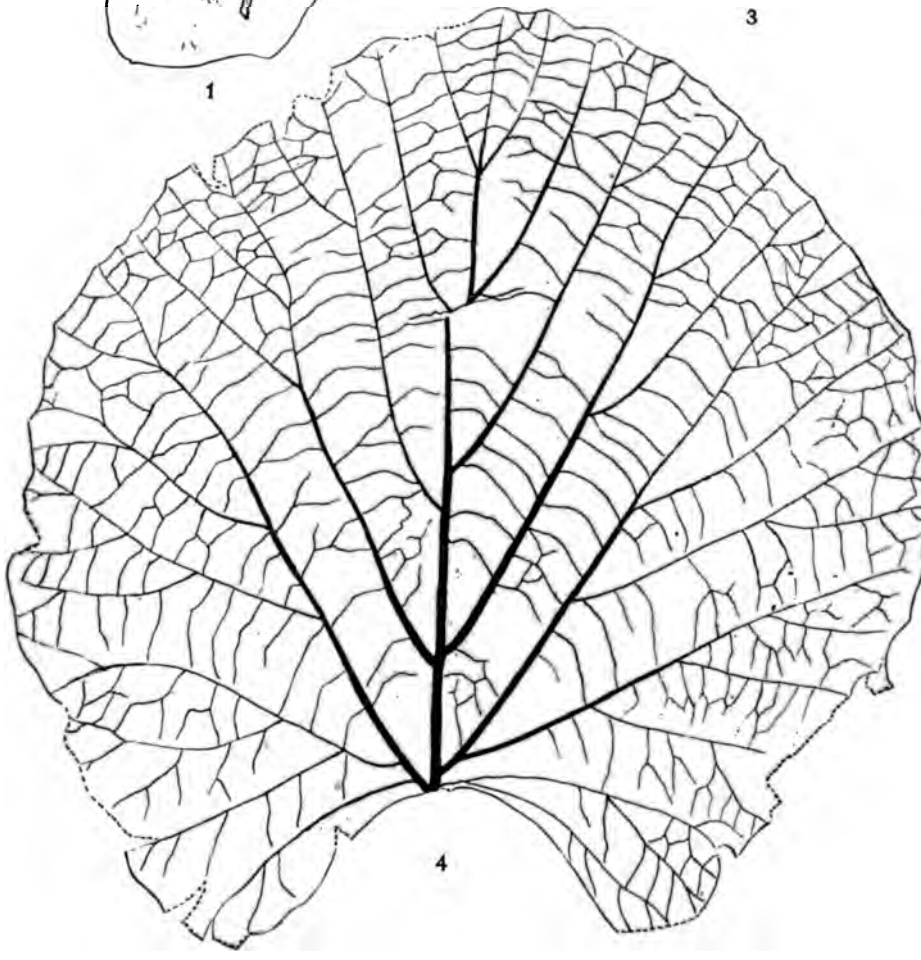

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